Joint Planning and Development Office
Next Generation Air Transportation System

NextGen Avionics Roadmap

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NextGen Avionics Roadmap Version 1.0 Overview

The Joint Planning and Development Office (JPDO) Aircraft Working Group (WG) has developed the *NextGen Avionics Roadmap Version 1.0 (v1.0)*. The document is intended to communicate to the aviation community how the many proposed Next Generation Air Transportation System (NextGen) improvements correlate to aircraft capabilities and functions, and how these capabilities/functions evolve over time. This initial *Roadmap* is intended as a starting point and a first step to help focus the discussion and debate needed to grow consensus in the aviation community. It is a way to facilitate subsequent NextGen planning as it relates to improved aircraft capabilities and corresponding avionics. The *Roadmap* should not be viewed as a long-term NextGen planning source—that is the role of the JPDO's Integrated Work Plan (IWP) and the Concept of Operations (ConOps), as well as other government partner's specific planning documents such as the FAA's NextGen Implementation Plan.

Material for this *NextGen Avionics Roadmap v1.0* draws from NextGen planning sources (IWP, ConOps, the FAA's NextGen Implementation Plan, and the FAA's Performance-Based Navigation Roadmap), which capture how aircraft operations are expected to change through utilization of improved avionics. The *Roadmap* brings these many proposed changes together − into an aircraft perspective − so the aviation community can better understand the key avionics system changes for NextGen. The primary focus of this first version is improved air carrier and air transport operations through 2018 (NextGen mid-term), with some capabilities presented that broach the far-term time frame (2019 to 2025).

The *NextGen Avionics Roadmap v1.0* will evolve to address the needs of the broader user community (e.g., General Aviation, military, Unmanned Aerial Systems) and to fully characterize avionics system evolution through the far-term. Future efforts include the integration and alignment of the *Roadmap* into the foundational JPDO and partner agency planning documents, to allow for greater clarity on aircraft- and avionics-specific changes.

The *NextGen Avionics Roadmap v1.0* is available for download on JPDO.gov. We strongly encourage the community to provide comments and suggestions that focus on the overall approach, philosophy, and structure of the *Roadmap* and the future work. Please watch the JPDO.gov Web site for scheduled briefings on v1.0. For written comments, please use the form posted with the *Roadmap* and email the completed form to 9-AWA-ATO-JPDO-Partnership@faa.gov with "Avionics Roadmap" in the subject line by February 27, 2009.

Respectfully,

JPDO Aircraft Working Group

# Contents

Purpose and Background

The purpose of the NextGen Avionics Roadmap is to translate many proposed Next Generation Air Transportation System (NextGen) improvements into aircraft-related capabilities and functions. This Roadmap was developed by the Joint Planning and Development Office (JPDO) Aircraft Working Group (WG). It is intended to provide other organizations involved in NextGen planning with an initial **aircraft-centric perspective** to assist them in understanding the integration issues that will be necessary with the other principal components of National Airspace System (NAS) development—Air Traffic technology and procedures, Communications, Surveillance, and Flight Planning Systems. Stakeholders will benefit from reading this document because it will provide them with an initial view of what avionics-related capabilities will be required for the different types of operations envisaged for NextGen. The primary focus of this first version is improved air carrier and air transport operations through 2018 (NextGen mid-term), with some work presented that broaches the far-term time frame (2019 to 2025). The scope of this work will be expanded in 2009.

The overall vision of NextGen was created to address ways to safely expand the current national airspace infrastructure to support the projected growth of air travel in the United States while continuing to maintain high safety standards, provide greater efficiency and predictability of operations, and do so in an environmentally friendly manner. This Roadmap supports these broad NextGen objectives by identifying the role of the aircraft in enabling these preferred operations, principally through advanced avionics systems.

Material for this Roadmap has been drawn almost entirely from existing sources that have captured different aspects of how aircraft operations are expected to change through utilization of improved avionics. These sources include the JPDO Concept of Operations (ConOps), JPDO Integrated Work Plan (IWP), and the Federal Aviation Administration (FAA) NextGen Implementation Plan (NIP—formerly Operational Evolution Partnership). Other source material comes from existing and draft FAA advisory material, Radio Technical Commission for Aeronautics (RTCA) Special Committee Reports, and the FAA's Performance-Based Aviation Rulemaking Committee (PARC). This document is aimed at bringing these different proposed changes together into one perspective so the aviation community as a whole can better understand the key avionics system evolutionary changes expected for NextGen, gaps that have been identified, and plans to address them.

An important consideration when reading this document is that it does not represent a complete picture of how NextGen will be executed; rather, it focuses on the aircraft component in recognition that the aircraft will be a key integrator for NextGen. This Roadmap will mature over time and is expected to be incorporated into other NextGen planning documents as they are revised.

This initial Roadmap is intended as a starting point, a first step to help focus the discussion and debate needed to grow consensus in the aviation community, and a way to facilitate subsequent NextGen planning as it relates to improved aircraft capabilities and corresponding avionics.
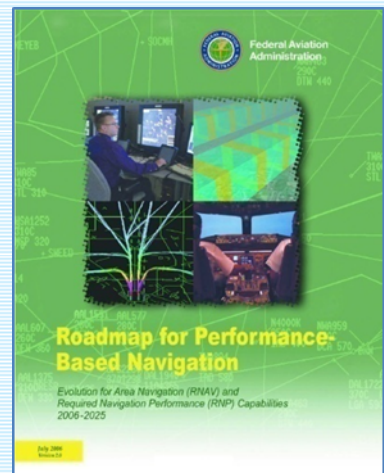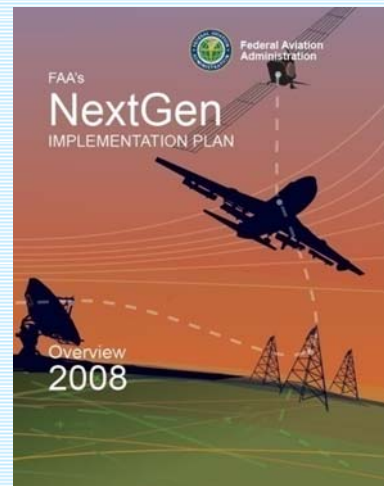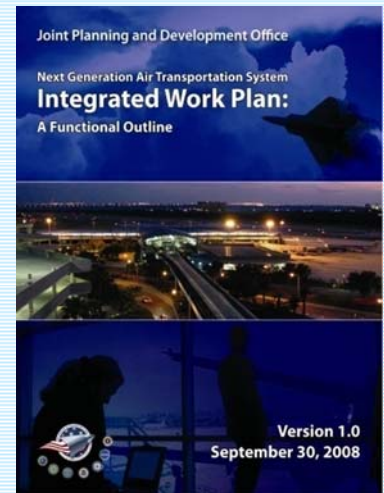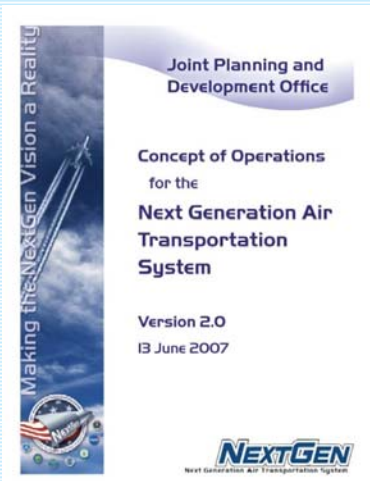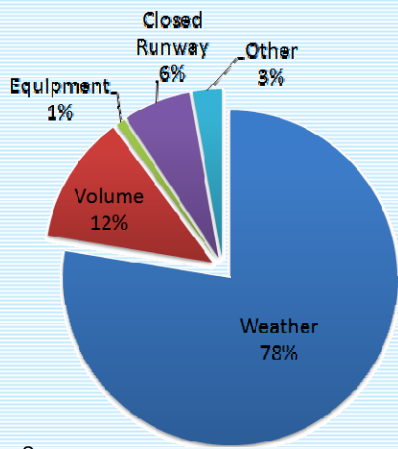
U.S. Enplanements and Operations Growth
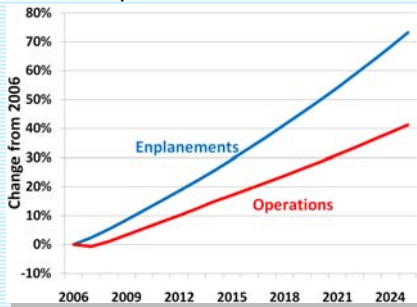
Capacity Constrained Areas 2025 (Forecast)

Causes of National Aviation System Delays (June 2003 – June 2008)

Aviation System Context

There are a number of challenges that must be addressed in the development of avionics to achieve the capabilities identified for NextGen. The basic challenges are system oriented and include increasing system capacity while maintaining efficiency, advancing safety, and insuring a positive cost/benefit ratio for NextGen investments.

SYSTEM CAPACITY AND EFFICIENCY

According to FAA and industry estimates, passenger growth over the next 17 years is expected to increase 73 percent with operations increasing by 41 percent. Limited runway construction is projected during the mid-term time period. Environmental concerns will also impact further airport expansion, constraining capacity even further.

NextGen avionics, advancements in air traffic automation systems, and modifications to existing air traffic policies and procedures will provide solutions to mitigate these conditions. More specifically, improvements to the overall operation of the NAS will be achieved by de-conflicting traffic flows in dense terminal areas and enabling routing that meets the environmental concerns of the communities served by the airport, while efficiently accommodating growing en-route traffic.

Advances in NextGen avionics and Air Traffic Control automation and procedures may also enable the system to safely maintain capacity in spite of convective weather en route and reduced visibility in terminal areas, which today cause 78 percent of delays. Allowing aircraft to operate in instrument conditions as they would in visual conditions will eliminate a substantial percentage of those delays. Finally, trajectory-based operations (TBO) will enable additional efficiencies, and can be tailored to meet the needs of a given airspace need or operator capability.

COST AND BENEFIT CONSIDERATIONS

Costs to an aircraft operator, whether airline, General Aviation (GA), or military, come in two forms-- capital and operating. Capital costs reflect the expense incurred when purchasing the aircraft or implementing major upgrades. Operating costs reflect the costs of operating the aircraft, including such factors as fuel, labor, and maintenance. When considering avionics purchases, a large part of the justification is dependent on the services provided that allow the avionics to be used to its full advantage. Operators will not invest in new avionics where there are no services to support them or in the absence of a clear business case. This is a very important factor that must be considered in the overall planning and implementation of NextGen and amplifies the importance of integrating the aircraft capabilities, the air navigation service provider (ANSP) capabilities, and the user needs to come up with the best overall solutions for NextGen.

Operating costs are greatly influenced by the efficiency of the NAS. Improved services can significantly improve the benefit ratio for both normal and non-normal operations (as affected by adverse weather conditions). One of the key elements in NextGen will be the application of TBO that will allow commercial operators to have greater predictability for their operations, reducing flight times and thus block times. This allows operators to improve their schedule reliability and lower block time costs, resulting in a better product for their customers at a lower unit cost. Non-commercial operators will also benefit because it will improve access either to or through high density terminal areas, resulting in reduced fuel requirements and thus lower costs. The use of TBO will also allow all operators to tailor their avionics to meet their particular mission requirements.

A key factor that will influence the cost/benefit ratio is the issue of retrofitting older aircraft with NextGen avionics. Retrofit will not only apply to existing legacy aircraft, but to today's new aircraft as well. Aircraft such as the Boeing 787 and Airbus A350 may not be delivered with NextGen avionics because a portion of the capability envisaged for NextGen may not be available until late in the mid-term or perhaps early into the far-term (2019 to 2025). This emphasizes the importance of finalizing

NextGen avionics requirements as soon as practical to allow the appropriate amount of time for development, certification, and implementation.

As noted previously, the Avionics Roadmap is aimed at bringing together many sources of information to enable a broader understanding of the capabilities aircraft need for NextGen. In time, the implications of those capabilities (cost, benefit, risk, availability, relationship to later changes, etc.) will need to be clearly understood, as all of these factors must be considered together to make the best decisions for NextGen. This contextual information is considered critical to enable the overall dialogue, debate, and decisions needed for NextGen. To support issuance of the first version of the Roadmap, an initial assessment of benefits and risks was conducted for each of the proposed aircraft capabilities. This is valuable work and will be used to guide the next steps in maturing the Avionics Roadmap.

SYSTEM SAFETY

From an avionics perspective, safety is the primary factor that drives the design, development, and approval process to ensure the new functions/capabilities meet the appropriate level of integrity. This applies to both the hardware and software designs. This process then carries over into the integration of the avionics with the airframe. The safety implications associated with the capabilities presented in this Roadmap will be addressed in future updates. In recognition of the work that lies ahead in terms of solidifying specific changes needed for NextGen, it is important to highlight that many past efforts involving avionics system upgrades have spanned long periods (15 to 25 years, with an average of 18 years from concept phase to initial deployment—see adjacent figure for examples). For NextGen to be successful, all stakeholders will need to work more collaboratively and in an accelerated mode to enable these important improvements to be utilized in shorter time frames. Examining the safety issues associated with proposed changes up front will be important in minimizing the associated timelines for development and implementation.
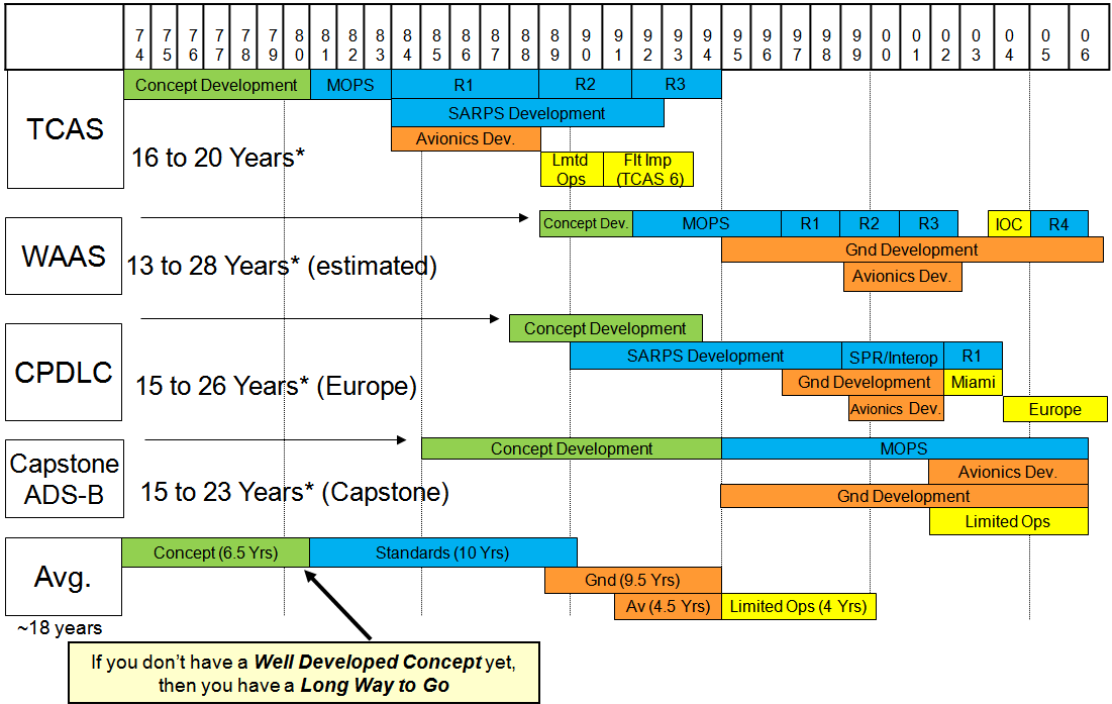
Call to Action

The National Air Transportation System faces four challenges that are key tenets of NextGen:

- Coping with increased demand for air transportation
- Improving current levels of safety and security, commensurate with increased operations
- Minimizing environmental impacts
- Ensuring that the overall changes to the NAS are economically viable

One of the most significant challenges in implementing NextGen is to ensure that the operational improvements (OIs) and capabilities are properly distributed between the aircraft, air traffic system automation, and operator flight planning systems. Integration of these elements is critical not only to the future system's operation, but also to properly distribute the required capital investments of the participants. This version of the Roadmap provides an aircraft perspective on how capabilities and functionality can be allocated between multiple sources primarily through the mid-term time frame (2018).

This document is provided as an initial release with the objective of broadening the dialogue, debate, and decisions needed to advance NextGen. This is enabled through:

- Illustrating, from the aircraft perspective, the expected evolution in NextGen operations. Initial focus is on air transport operations through the mid-term time frame.
- Proposing an approach for how aircraft can participate in TBO (at an applications level) in consideration of using both commercial communication services (System-Wide Information Management [SWIM]) and certified data link capabilities, and the limitations of each. It is recognized that this is an aircraft perspective; engagement with the Air Navigation Service community and the flight planning functions of the airlines is needed to develop a more complete depiction of TBO operations.
- Identifying the equipment that enables future NextGen operational capabilities and its current level of maturity.
- Showing the relationship between several different planning activities that have identified expected avionics system changes. Illustrations are provided that show how these ideas relate to one another and how they support the overall aircraft capabilities envisioned for NextGen.
- Recognizing that the needs and operations of all users will not be the same. As a result, NextGen investments must be managed to ensure changes provide realizable benefits to the operator(s) and the NAS. This enables an overall aircraft capabilities framework to be developed without assuming a one-size fits all solution.
- Understanding that any aircraft change anticipated for NextGen must be based upon global interoperability to the maximum extent possible. Regional differences must be minimized. This is expected to be achieved through NextGen/Single European Sky ATM Research Programme (SESAR)/International Civil Aviation Organization harmonization. Development of the first version of the Roadmap has been supported by select experts from the European aviation community. The first version of the Roadmap provides a starting point for more in-depth considerations of the NextGen and SESAR integration implications.

Collectively, the capabilities presented in this Roadmap are aimed at addressing the four key challenges noted above—through improved operations that enable better use of airspace, enable great operator and controller efficiency, and are more environmentally responsible.

The Roadmap shows the planned aircraft capabilities through the mid-term with some indication of the far-term capabilities.

Answering the Call

NextGen is an overall transformation of the NAS, and therefore it is imperative that all users understand the major changes envisioned for this transformation and engage in the overall process of making sure the right changes are pursued, and in time implemented.

Aircraft operators will play a decisive role in shaping the changes needed for NextGen through focused investment decisions that examine operational capabilities, equipment that enables those operations, the cost of investments and the return (benefits) from those investments. Those targeted investments encompass new operational capabilities, along with the avionics, procedures, and training that enable them.

To help the aviation community prepare for making these future decisions—*answering the call*—this Avionics Roadmap identifies six groups of operational capabilities important to NextGen. These capabilities are derived from the many proposed avionics system changes that have been captured in different planning activities (JPDO ConOps, JPDO IWP, FAA NIP, and the Roadmap for Performance-Based Navigation [PBN]).

Some proposed aircraft-enabled improvements captured in the JPDO IWP have been deferred from this version of the Roadmap, and these are identified and explained. Finally, the initial benefits and risk assessment work that has been completed is summarized. This initial assessment is being used to guide the future maturation of the Avionics Roadmap and how the Aircraft WG engages with other groups—both inside and outside the JPDO—that are involved in work related to developing these capabilities. Supporting details on each of these aspects of answering the call are presented in the appendices to this document.

From the stakeholders' perspective, the following points are noted as particularly important in how you can help in answering the call to further the overall NextGen planning process.

- Provide comment on the usefulness of this Roadmap and what your community needs for it to be a fully mature source of information. It is recognized that industry and government stakeholders need additional information regarding functional allocation, detail performance requirements and equipment requirements to facilitate future avionics system planning. In support of obtaining feedback on the Roadmap, outreaches will be conducted with particular WGs, committees, and associations. Consideration is also being given to holding a workshop in early 2009 to reach other stakeholders and solicit input on ways to improve this product, including how to integrate the needs of different user communities (GA, military, Unmanned Aerial Systems [UASs], etc.).
- Identify how this document should be used to revise other NextGen planning documents.
- Specifically review the material presented in Appendix 1 on how the aircraft can participate in TBO, recognizing this is a first proposal and that other perspectives (ANS, flight planning) will need to be examined and used to shape a more complete explanation.

Avionics-Enabled NextGen Operational Capabilities

The avionics-enabled improvements in this Roadmap are presented in six groups of related operational capabilities. This approach is intended to identify the type of aircraft operational capabilities that are considered necessary or advantageous for NextGen operations. The objective is to help operators identify the types of capabilities that will be available and likely important to their future NextGen operations, and to show the relations between the capabilities and the specific changes reflected in other planning documents. The capabilities structure may be incorporated into other JPDO-developed planning documents when they are revised, and this may necessitate minor adjustments to the capabilities structure depicted in this Roadmap.

The six capabilities were structured in a building block fashion where capabilities are progressively more encompassing, and therefore enable more complex types of operations. The bullets below provide a high-level snap shot of how the capabilities were structured and their relationship to one another.

- **Safety Enhancements** – Address the fact that NextGen is dependent on higher density operations in the air and on the ground. To support these operations, which are enabled by the other five capability groups, enhancements to existing safety functions will be needed along with consideration of adding additional safety functions.
- **Published Routes and Procedures** – Predicated on improved operations associated with precision navigation capability— Area Navigation (RNAV) and Required Navigation Performance (RNP).
- **Negotiated Trajectories** – Builds upon the capabilities of precision navigation by adding data communications capability to enable dynamic negotiation of preferred routes.
- **Delegated Separation** – Adds to the capability of negotiated trajectories through the availability of enhanced situational awareness—in the air and on the ground—to enable delegated separation practices to be broadened from use in visual conditions today to use in non-visual conditions.
- **Low Visibility Approach/Departure and Taxi** – Recognizes that more aircraft capability is available today to enable operations in weather-limiting conditions and with less dependence on costly ground infrastructure. This allows operations to more readily adapt to changing situations without reliance on existing or new ground infrastructure.
- **ATM Efficiencies** – Identifies capabilities that improve the ATM process, thereby reducing the FAA's costs of operations and/or enabling new services to be provided.

The six groups of capabilities outlined above are fully aligned with the FAA's NIP published in June 2008. This is critical from the standpoint that the Avionics Roadmap is aimed at addressing the overall evolution of aircraft capabilities and how they are enabled by certain avionics. To do this, there must be a clear understanding of what is in place today, what is committed and coming (per the NIP), and what needs to be added in the far-term to fully utilize these broad capabilities.

For each of the six capability groups a separate chart is provided that depicts near-term/mid-term/far-term time frames along with expected initial availability of each operational capability (uncertainty may span more than one time frame). Below the operational capabilities time-ranges are shown the OIs from the JPDO IWP, the NIP, and the PBN Roadmap that support that capability. Using this approach, the complexity of the expected change for NextGen can be simplified by showing the relationship of many individual changes that have been idenitfied and how in many cases they are aiming to depict the same higher level capabilitiy. Interpretation of these charts is illustrated here:
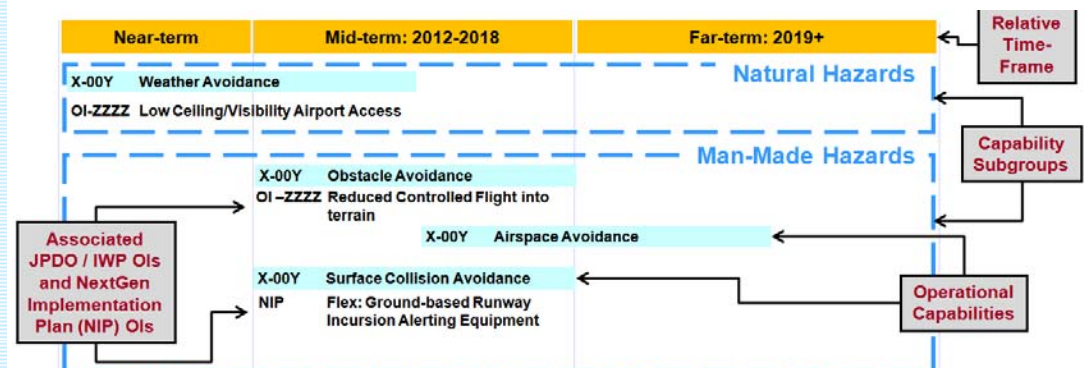
Adjacent to each chart are descriptions of the operational capabilities with a list of key avionics enablers. The key avionics enablers may have options within the set given. The maturity and operational readiness of these enablers for use supporting this capability is color/font coded. **Green Bold Enablers** are mature for use in supporting that capability. <u>Orange Underlined Enablers</u> are specifically known, but are not yet completely standardized, implemented, certified, or approved for use in that capability. *Italicized Enablers* require more understanding than currently exists as to the specific version of the enabler needed (even if the versions are themselves mature). Appendix 2 provides a tabulation of the enablers and identifies what capabilities are supported by the enabler. This allows the user community to start gaining a sense of the number and types of enablers that may be necessary to support operations that will be integral with NextGen.

Historical lead-in times for CNS initiatives (15 to 25 years) are dominated by the concept and standards phases of development, which are typically performed in series. A concerted effort to either parallelize these steps or to shorten them to some extent is required, and should be undertaken as part of the JPDO process.

A number of the mid-term capabilities require policy decisions be made in order for the capability to be realized. Virtually all capabilities require that decisions be made about which equipage strategy will be employed. Those strategies will likely differ between capabilities. Additionally, there is also a need to set policies to achieve the desired balance between ground infrastructure and avionics equipage. Research and development efforts will sometimes yield multiple solutions for achieving a capability and permit trade space between ground infrastructure and avionics equipage. In an effort to avoid costs, the ANSP and operators will likely favor solutions that shift costs away from them. These policies will need to be integrated with equipage policies. Appendix 5 provides a summary of the JPDO IWP policy issues associated with the capabilities presented in this Roadmap. Further refinement of policy issues will be needed as the capabilities, for both mid- and far-term time frames are fully matured.

SAFETY ENHANCEMENT/HAZARD AVOIDANCE & MITIGATION

Safety enhancements are based on the awareness, avoidance, and mitigation of natural and man-made hazards. Hazards include terrain, obstacles, other aircraft (either on the airport surface or airborne), Special Use Airspace (SUAs), dynamic terminal airspace, weather, and wake. The aircraft continues to play a paramount role in aircraft safety, using flight deck displays of the airport surface, other aircraft positions, and improved hazard information provided by ground systems and other aircraft.

Safety enhancements are key enablers to fully exploit the potential of the other capabilities presented in the Roadmap. In other words, these capabilities and their corresponding enablers will allow a greater potential of the other five capability groups to be achieved. Safety enhancement capabilities also address areas of operation that are considered to have greater vulnerability from a safety standpoint due to higher traffic volumes and different operational procedures expected with NextGen.

Weather/NAS Status/ Traffic Display

Weather/NAS Status Display

Traffic Display

Benefits

1. Reduced GA weather-related accidents due to improved weather situational awareness
2. Reduced GA mid-air collisions and near-miss incidents due to improved traffic situational awareness

Surface Moving Map With Own Ship Position

Benefits

Reduction in runway incursions with moving map, own ship position, and proximate traffic display (ADS-B In)

Near-term	Mid-term: 2012-2018	Far-term: 2019+

Natural Hazards

	SAFE-001 Enhanced Low Altitude Operations	
	OI-3010 Reduced Controlled Flight into Terrain – Level 1	
SAFE-002 Weather Avoidance		
NIP FIS-B	NIP On-Demand NAS Information (C-ATM)	

Man-Made Hazards

	SAFE-003 Obstacle Avoidance	
	OI-3010 Reduced Controlled Flight into Terrain – Level 1	
SAFE-004 Airborne Collision Avoidance		
SAFE-005 Surface Collision Avoidance		
NIP TIS-B	OI-0332 Ground-based and On-board Runway Incursion Alerting	
	NIP Provide Full Surface Situation Information (FT)	
SAFE-006 Airspace Avoidance		
NIP FIS-B (TFRs)	NIP On-Demand NAS Information (C-ATM)	
	NIP Improved Management of Airspace for Special Use	
	SAFE-007 Wake Avoidance & Mitigation: Combination Air and Ground	
		SAFE-008 Wake Avoidance & Mitigation: Aircraft Based

Capability	Key Enablers
SAFE-001: Enhanced Low Altitude Operations – Leverage enhancements to TAWS along with higher integrity and resolution terrain databases to reduce CFIT.	RNP (as required by specific procedure), *Improved Terrain Database, TAWS Enhancements*
SAFE-002: Weather Avoidance – Reduce impact of hazardous weather through broadcast of text and graphical weather information to aircraft.	**FIS-B, Moving Map**
Reduce impact of hazardous weather through data link of enhanced weather and turbulence forecasts to aircraft.	**FIS-B, Moving Map, and** **For text only weather information: Initial Data Link (FANS 1/A+,** FANS 2/B, ATN Baseline 1 LINK Post Pioneer **)** **For text and graphical weather information:** *Data Link (Not supported by initial data link enablers)*
SAFE-003: Obstacle Avoidance – CFIT is further reduced through availability of higher-frequency updates related to the position of temporary and permanent (fixed) man-made obstacles.	*Improved Terrain Database, Improved Obstacle Database*, Moving Map
SAFE-004: Airborne Collision Avoidance – Risk of airborne collisions is reduced through enhancements to TCAS to reduce false alerts in complex maneuvers.	*ADS-B In, TCAS Enhancements*
SAFE-005: Surface Collision Avoidance – Surface Moving Maps with own-ship and traffic are used to reduce runway incursions.	**ADS-B In**, **Moving Map**, **CDTI**
Surface Moving Maps with own-ship, traffic, and alerting are used to reduce runway incursions.	**ADS-B In**, **Moving Map**, *CDTI with Alerting (Ground Operations)*
SAFE-006: Airspace Avoidance – Broadcast data link communications is used to provide pilots with updated information on TFRs, improving pilot situational awareness.	**FIS-B**
Data link communications is used to provide pilots with updated information on TFRs and SUA status, improving pilot situational awareness.	**FIS-B**, **Initial Data Link (FANS 1/A+,** FANS 2/B, ATN Baseline 1 LINK Post Pioneer**)**
SAFE-007: Wake Avoidance and Mitigation – Air/Ground Combination – Pilot situational awareness of wake vortices is improved through communication of ground-based wake detection and prediction information.	**GNSS**, ADS-B Out, *Aircraft Characteristic Database*, *Aircraft Wake Database, Wake Transport Model, Wake Decay Model*, *Data Link (Not supported by initial data link enablers)*
SAFE-008: Wake Avoidance and Mitigation – Aircraft-Based – Aircraft-based wake vortex sensors are leveraged to further improve detection and prediction, reducing wake hazards in high-density operations.	**GNSS**, *Aircraft Characteristic Database, Aircraft Wake Database, Wake Transport Model, Wake Decay Model*

PUBLISHED ROUTES AND PROCEDURES

RNAV and RNP Capable Part 121 Operations at Top 34 Airports
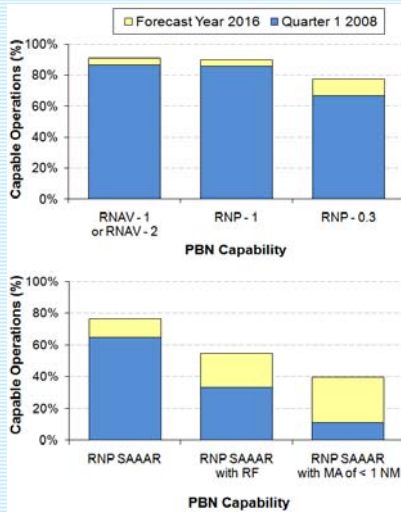
Source: Performance Based Navigation Capability Report 2008 MITRE/CAASD

Because of the large number of aircraft that are already equipped for RNAV and RNP operations, most near-term initiatives involve published routes and procedures, including Q routes, T-routes, RNAV arrival and departure procedures, RNAV (RNP) approaches, and RNAV instrument approach procedures, many with both LNAV and VNAV, as well as LPV minima. To take full advantage of existing aircraft capability, additional criteria for published routes are being developed to enable curved-path procedures as part of a departure, arrival, or initial approach. Other criteria being developed take advantage of VNAV capability on arrivals and departures, using window constraints along a procedure to de-conflict published routes using a 2½D trajectory.

The capabilities presented below are fully aligned with the FAA Roadmap for Performance-Based Navigation (published July 2006). To date, no additional capabilities in the area of Routes and Procedures have been identified from those contained in the PBN Roadmap.

RNP approaches are happening now. In 2005, Palm Springs' RNP SAAAR approach to 31L dramatically improved access and safety. The approach is 40 miles shorter, and has enabled many additional operations to be conducted.

Near-term	Mid-term: 2012-2018	Far-term: 2019+
		RNAV and RNP SIDs and STARS
	PRP-001 Reduce Lateral Track Spacing Using RNP	
	OI-0348 Reduced Separation – High Density Terminal, Less Than 3 Miles	
	PBN RNP-2 Routes	
	PBN RNP-1 or lower SIDs/STARs where beneficial	
	PRP-002 Integrated Arrival/Departure Airspace Management	
	OI-0311 Enhanced Arrival/Departure Routing and Access	
	NIP Hi Density: Integrated Arrival/ Departure Airspace Management	
	PBN Enhanced automation incorporating aircraft navigation capabilities	
	PBN RNAV SIDs/STARs at many of the top 100 airports	
	PRP-003 Closed Loop Lateral Offsets for Time of Arrival Control	
	NIP Hi Density: Time Based Metering with RNAV/RNP	
	NIP 3D PAM Demonstration at DEN	
	PBN Airspace redesign and procedures for RNAV and RNP with 3D, CDA, and time of arrival control	
PRP-004 Optimized Descent Profiles (FMS Only)		
OI-0330 Time-Based and Metered Routes with CDA	OI-0330 Time-Based and Metered Routes with CDA	
NIP Flex: Use Optimized Descent Profiles	NIP Tailored Arrivals	
PBN Concepts for RNAV and RNP with 3D, constant descent arrivals (CDA), and time of arrival control	PBN Airspace redesign and procedures for RNAV and RNP with 3D, CDA, and time of arrival control	
	PRP-005 3D RNP Arrival and Departure Operations	
	PBN Airspace redesign and procedures for RNAV and RNP with 3D, CDA, and time of arrival control	
		Reduced Oceanic Separation
	PRP-006 Reduced Oceanic Separation – Altitude Change Pair-wise Maneuvers	
	OI-0353 Reduced Oceanic Separation - Altitude Change Pair-wise Maneuvers	
	NIP Oceanic In-Trail Climb and Descent	
	PBN Limited RNP-4 and 30NM lat in WATRS	
PRP-007 Reduced Non-Radar Separation with ADS-B out (Gulf of Mexico)		
OI-0347 Reduced Separation Non-Radar Airspace 5 Miles		
NIP Commitment to ADS-B in Gulf of Mexico in 2010		

Capability	Key Enablers
PRP-001 Reduce Lateral Track Spacing Using RNP – Growing number of RNP-capable aircraft allow the design of en route and terminal procedures with reduced track-to-track separation.	RNP (as required by procedure), **RNP SAAAR, RF Leg (As required by procedure)**.
PRP-002: Integrated Arrival/Departure Airspace Management – Terminal airspace volumes are redesigned and in some cases expanded, RNAV procedures are designed to provide de-conflicted access to and from all airports in busy metropolitan areas.	**RNAV**
PRP-003: Closed Loop Parallel Offsets for Time of Arrival Control – Closed-loop parallel offsets from RNAV or RNP SIDs and STARs provide additional flexibility for metering, merging, and spacing operations.	**RNAV,** RNP (as required by procedure)
PRP-004: Optimized Profile Descents (FMS only) – Additional procedures are designed that allow minimally equipped aircraft to fly optimized profile descents with minimal impact on terminal areas capacity.	RNP (As required by procedure), VNAV
Additional procedures are designed that allow vertical-navigation (VNAV) capable aircraft to fly optimized profile descents with minimal impact on terminal areas capacity.	RNP (As required by procedure), VNAV, *Data Link (Integrated with FMS or stand-alone navigator, and not supported by Initial Data Link enablers)*
PRP-005: 3D RNP Arrival and Departure Operations – RNP–based VNAV capability allows the design of 3D RNP procedures which permit vertical deconfliction of arrival and departure flows, including optimized profile descents.	RNP (as required by procedure), VNAV, *Vertically guided RNP, Data Link (Integrated with FMS or stand-alone navigator, and not supported by Initial Data Link enablers)*
PRP-006: Reduced Oceanic Separation – Altitude Change Pair-wise Maneuvers – Pair-wise separation requirements for altitude changes in oceanic airspace are reduced for RNP-4 and FANS 1/A capable aircraft.	**RNP 4**, **ADS-C**, ADS-B, CDTI, **FIS-B**, **Initial Data Link (FANS 1/A)**
PRP-007: Reduced Non-Radar Separation with ADS-B Out (Gulf of Mexico) – ADS-B Out is leveraged to allow 5-mile separation offshore and other non-radar airspaces.	**ADS-B Out**

NEGOTIATED TRAJECTORIES

By integrating the aircraft's navigation capability with data link, the precision and reliability of RNP routes can be applied to dynamically-defined routes. Many current aircraft have some capability (e.g., FANS-1A) to negotiate a trajectory. A negotiated trajectory may be as simple as an expected path from top-of-descent, or as complex as a four-dimensional (4D) path with performance requirements. Negotiated routes may be implemented as 2D trajectories, 3D trajectories, 3D trajectories with an RTA at a particular fix (3½D trajectory), or ultimately, a full 4D trajectory including time constraints along the entire trajectory (4DT).

A gap in the work to encapsulate what is envisioned for NextGen has been specificity regarding TBO, and an explanation of how the aircraft can participate in consideration of using both commercially available and certified data link capabilities. As the capabilities here illustrate, TBO between air and ground can be used at a range of levels of capability. All of these levels fit within a TBO framework in which 4D representations of flight trajectories are used to enhance user access to preferred routes and to also enhance air traffic management. (This framework is described in Appendix 1.) The stakeholder community is specifically requested to review this proposal and provide input to help develop consensus on what TBO operations mean and how they are executed in the near- and mid-term.

Near-term	Mid-term: 2012-2018	Far-term: 2019+
	Improve Traffic Management with Limited Trajectory	
NT-001 Oceanic Airspace; Flexible Entry Timing	NT-002 Overhead Flow; Flexible Entry Timing	
OI-0304 Improved Collaborative Oceanic Routing	NT-003 Initial Surface Traffic Management	
NIP Flexible Entry Times for Oceanic Tracks	OI-0320 Surface Management – Level 1	
NT-004 Terminal Airspace; Flexible Entry Timing	NIP Provide Full Surface Situation Information	
	Improve Traffic Management with RTA	
	NT-005 Route Clearance with RTA	
	NIP TBM using RNAV&RNP Route Assignments	
	NT-006 Route Clearance with RTA and Downlink of Expected Trajectory	
	NT-007 Trajectory Clearance with RTA and Downlink of Expected Trajectory	
	OI-0357 Trajectory Based Mgmt – Level 1 Route/Trajectory Digital Exchange	
	OI-0358 Trajectory Based Mgmt – Level 2 Trajectory Based Decision Support	
	OI-0360 Trajectory-Based Mgmt – Level 3 Automation-Assisted Trajectory Negotiation	
	OI-0369 Trajectory Based Mgmt – Level 4 Automated Negotiation/Separation Mgmt	
	Improve Traffic Management with Full 4DT	
	NT-008 Airborne Lateral/Vertical/Time Clearance	
	NT-009 Taxi Lateral/Time Clearance	
	OI-0357 Trajectory Based Mgmt – Level 1 Route/Trajectory Digital Exchange	
	OI-0358 Trajectory Based Mgmt – Level 2 Trajectory Based Decision Support	
	OI-0360 Trajectory-Based Mgmt – Level 3 Automation-Assisted Trajectory Negotiation	
	OI-0369 Trajectory Based Mgmt – Level 4 Automated Negotiation/Separation Mgmt	

Capability	Key Enablers
NT-001: Oceanic Airspace; Flexible Entry Timing – Support for user-preferred trajectories is increased through the negotiation and communication of entry times into oceanic airspaces. Operations are supported by voice or data link communications where available.	**RNAV, Initial Data Link (FANS 1/A+,** FANS 2/B, ATN Baseline 1 LINK Post Pioneer**)**
NT-002: Overhead Flow; Flexible Entry Timing – Support for user-preferred trajectories is increased through the negotiation and communication of entry times into en route overhead flows. Operations are supported by voice or data link communications where available.	**RNAV, Initial Data Link (FANS 1/A+,** FANS 2/B, ATN Baseline 1 LINK Post Pioneer**)**
NT-003: Initial Surface Traffic Management – Surface operations and traffic flow management are improved through the availability of aircraft surface position via ADS-B.	**ADS-B Out**
NT-004: Terminal Airspace; Flexible Entry Timing – Support for user-preferred trajectories is increased through the negotiation and communication of entry times into terminal airspaces. Operations are supported by voice or data link communications where available.	**RNAV, Initial Data Link (FANS 1/A+,** FANS 2/B, ATN Baseline 1 LINK Post Pioneer**)**
NT-005: Route Clearance with RTA – Route clearances with a single RTA are communicated to aircraft by voice or data link communications for domestic en route.	**Initial Data Link (FANS 1/A+,** FANS 2/B, ATN Baseline 1 LINK Post Pioneer**),** CTA.
NT-006: Route Clearance with RTA and Downlink of Expected Trajectory – Ground-based conflict detection is enhanced through the downlink—via data link communications—of the aircraft's expected trajectory for domestic en route.	**Initial Data Link (FANS 1/A+,** ATN Compliant**),** CTA.
NT-007: Trajectory Clearance with RTA and Downlink of Expected Trajectory – ANSP provides aircraft—via data link communications—with a lateral and vertical trajectory clearance (e.g., latitudes, longitudes and altitudes), along with a single RTA for domestic en route.	**Initial Data Link (Baseline),** CTA
NT-008: Airborne Lateral/Vertical/Time Clearance – ANSP provides aircraft, via data link communications, with a lateral and vertical trajectory clearance (e.g., latitudes, longitudes, and altitudes) along with a single RTA.	**Initial Data Link (FANS 1/A+,** FANS 2/B, ATN Baseline 1 LINK Post Pioneer**)**
NT-009: Taxi Lateral/Time Clearance – Full taxi path (including ETAs) clearances are issued to the aircraft via data link communications.	*Data Link (Not supported by initial data link enablers)*

DELEGATED SEPARATION

Three capability sub-groups have been identified for delegated separation that reflect different levels of avionics functionality and integration.

In the first capability sub-group, ADS-B In and improved avionics capabilities provide the flight deck accurate position and trajectory data. Aircraft that are equipped to receive the broadcasts and have the associated displays, avionics, and crew training are authorized to implement speed changes to achieve and maintain a controller-specified spacing value behind a preceding aircraft, without delegation of separation authority to the flight crew. Additionally, mixed equipage can be supported within a single arrival stream to achieve continuous descent arrivals, with some aircraft having precision airborne merging and spacing capability, and other aircraft being managed by the ANSP. Fuel consumption and noise on approach are reduced while maintaining throughput in moderate-to-heavy traffic.

In the second capability sub-group, enhanced surveillance and new procedures enable the ANSP to delegate aircraft-to-aircraft separation. Improved display avionics and broadcast positional data provide detailed traffic situational awareness to the flight deck. When authorized by the controller, pilots implement delegated separation between equipped aircraft using established procedures.

In the last capability sub-group, current technologies, such as ADS-B and precision navigation, can be integrated in new ways to support paired approach operations where navigation and cockpit automation reduce the risk exposure. ADS-B enables aircraft to remain above or in front of the wake vortex of an aircraft on the parallel approach, and ADS-B significantly reduces the reaction time to break off the approach in the unlikely scenario of a blunder. The achievable runway spacing with these technologies must be determined, so that the business case to equip with these capabilities can be evaluated for current runways and for potential new runway construction.

The use of ADS-B and precision approach navigation may enable parallel approach operations in instrument meteorological conditions at locations such as San Francisco (Runways 28L and 28R).

Near-term	Mid-term: 2012-2018	Far-term: 2019+
		Flight-Deck Merging and Spacing
DS-001 Merging and Spacing		
OI-0326 Airborne Merging and Spacing – Single Runway OI-0338, OI-0355, OI-0333		
NIP Delegated Responsibility for Separation (TBO)		
DS-002 Use Optimized Profile Descents (FMS + FDMS)		
OI-0329 Airborne Merging and Spacing with CDA		
		Delegated Separation Operations
		DS-003 Delegated Separation for Specific Operations
		OI-0356 Delegated Separation – Pair-wise Maneuvers
		OI-0359 Delegated Separation – Oceanic
		DS-004 Delegated Separation for Complex Operations
		OI-0363 Delegated Separation – Complex procedures
		DS-005 Delegated Separation in Flow Corridors
		OI-0337 Flow Corridors – Level 1 Static
		OI-0368 Flow Corridors – Level 2 Dynamic
		Closely Spaced Parallel and Converging Approaches In Low Visibility
	DS-006 Paired Approach in IMC to Closely Spaced Parallel Runways	
	OI-0335 Dependent Multiple Approaches in IMC	
		DS-007 Independent IMC Approaches to Closely Spaced Parallel Runways
DS-008 Enhanced Visual Approach		OI-0334 Independent Parallel or Converging Approaches in IMC
OI-0316 Enhanced Visual Separation for Successive Approaches		NIP Improved Operations to Closely-Spaced Parallel Runways
NIP Delegated Responsibility for Separation		
DS-009 ADS-B Approach Spacing		

Capability	Key Enablers
DS-001: Merging and Spacing – ADS-B and CDTI applications allow improved metering, merging, and spacing operations by allowing an aircraft to achieve and maintain a controller-specified spacing behind another aircraft.	**RNAV**, ADS-B In, CDTI
DS-002: Use Optimized Profile Descents (FMS + FDMS) – Flight-deck merging and spacing is applied to aircraft flying optimized profile descents in high traffic environments.	**RNAV**, ADS-B In, CDTI, **Initial Data Link (FANS 1/A+,** ATN Compliant**)**
DS-003: Delegated Separation for Specific Operations – ADS-B and CDTI applications permit improved efficiency through the delegation of separation responsibilities for specific pair-wise maneuvers (e.g., passing, crossing, turn-behind).	ADS-B In, CDTI
DS-004: Delegated Separation for Complex Operations – Delegated separation capabilities are further leveraged to allow self-separation in more complex operational scenarios.	ADS-B In, CDTI
DS-005: Delegated Separation in Flow Corridors – Broad availability of ADS-B Out and CDTI applications allow design of specific flow corridors in which parallel streams of aircraft are self-separating.	ADS-B In, CDTI
DS-006: Paired Approach in IMC to Closely Spaced Parallel Runways – Airport capacity in IMC is enhanced through paired approaches (i.e., dependent) to closely spaced parallel runways that are enabled by ADS-B/CDTI and precision navigation.	ADS-B In, **RNP SAAAR**, RNP (As required by procedure), CDTI
DS-007: Independent IMC Approaches to Closely Spaced Parallel Runways – Runway spacing for independent parallel approach operations using Instrument Landing System (ILS) are reduced based on improved analysis and operational experience.	ADS-B In, **RNP SAAAR**, CDTI
DS-008: Enhanced Visual Approach – Single runway capacity in MMC is increased through CDTI-Assisted Visual Separation (CAVS) applications that allow for an aircraft to establish and maintain an assigned spacing separation from the preceding aircraft.	ADS-B (Out for lead aircraft; In for trail aircraft), CDTI (trail aircraft)
DS-009: ADS-B Approach Spacing – Single runway capacity is increased by using ADS-B to maintain delegated separation from the previous aircraft, ending either in a visual approach (after acquiring out-the-window references) or an instrument approach.	ADS-B (Out for lead aircraft; In for trail aircraft), CDTI (trail aircraft), *Guidance Display (trail aircraft)*

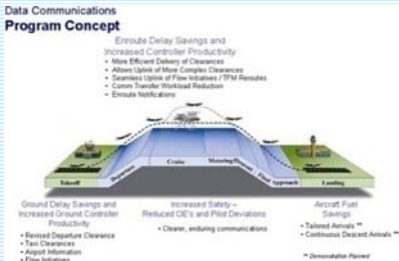## LOW-VISIBILITY/CEILING APPROACH/DEPARTURE/TAXI

In low-visibility/ceiling conditions, approach, departure, and taxi movement become constrained to ensure safety. The ILS is currently the predominant navigation aid to enable low-visibility/ceiling approach and take-off operations. Key technologies that may improve airport accessibility include aircraft-based technologies such as head-up display (HUD) or autoland capabilities, enhanced flight vision systems (EFVSs), and synthetic vision systems (SVSs), as well as the ground-based augmentation system (GBAS) in combination with GPS.

These new aircraft-based flight technologies will allow greater access and throughput at airports that would otherwise be unavailable due to insufficient ground infrastructure. By equipping with technologies such as HUDs, EFVS, or future technologies the aircraft operator will have greater flexibility and predictability of operations at a variety of airports with less dependence on existing ground infrastructure.

Image courtesy of Universal Avionics

Synthetic Vision Systems provide an electronic rendering of the external scenery from on-board databases. These systems give the pilot an electronic picture of the surrounding terrain and features, regardless of the actual weather conditions. In cases of reduced visibilities, properly certified SVS could enhance approach, departure and airport operations by providing the pilots the necessary elements they need in order to operate the aircraft safely. In addition, leveraging these advanced avionics could improve access to airports with limited infrastructure for low visibility operations.

Near-term	Mid-term: 2012-2018	Far-term: 2019+
Enhanced Approach, Landing, and Takeoff Operations		
LV-001 Low Visibility Approach Operations		
OI-0381 Low Ceiling/Visibility Airport Access		
NIP Ground-Based Augmentation System		
	LV-002 Low Visibility Landing Operations	
	OI-0317 All Weather Airport Access	
	LV-003 Low Visibility Takeoff Operations	
	OI-0381 Low Ceiling/Visibility Airport Access	
Enhanced Surface Operations		
	LV-004 Low Visibility Surface Operations	
	OI-0322 Low Visibility Surface Operations	

Capability	Key Enablers
LV-001: Low Visibility/Ceiling Approach Operations – Airport access in low visibility conditions is improved through reduction in approach minima for aircraft equipped with some combination of augmented GNSS, EFVS, and SVS capabilities.	**RNP SAAAR**, GLS III, **EFVS**, SVS
LV-002: Low Visibility/Ceiling Landing Operations – Airport access is further improved for aircraft in extremely low visibility/ceiling for aircraft equipped with some combination of augmented GNSS, EFVS, and SVS capabilities.	**RNP SAAAR**, GLS III, EFVS, SVS
LV-003: Low Visibility/Ceiling Takeoff Operations – Leverages some combination of augmented GNSS, CDTI, EFVS, and SVS capabilities to allow appropriately equipped aircraft to depart in low visibility conditions.	**ADS-B In**, SVS, EFVS, **CDTI**
LV-004: Low Visibility Surface Operations – Low-visibility/ceiling arrival and departure operations are enabled through surface operations (taxi and gate routing) that use some combination of augmented GNSS, CDTI, EFVS, and SVS capabilities to ensure safe operations.	GNSS, ADS-B In, SVS, EFVS, **CDTI**

AIR TRAFFIC MANAGEMENT EFFICIENCIES

In some cases, aircraft avionics can provide improvements to the ATM process that can result in reduced costs of operations to the FAA or enhancements in services. Aircraft key enablers, including data communications and enhanced weather sensors, combined with enhanced ground-based decision support tools to provide improvements in Aircraft-ANSP information exchange, access, and throughput at non-towered or uncontrolled airports, and weather forecasting for reduced weather impacts. These capabilities provide direct and indirect benefits to the aircraft associated with improved overall NAS efficiency.

Data Link En Route Clearance Delivery and Frequency Changes

Data Communications
Program Concept

Benefits

1. Improved Controller Productivity
2. Improved Operational Efficiency in Convective Weather by reducing flight time
3. Improved Operational Predictability enabled by reduced impact of disruptions
4. Reduced Fuel Usage and Related Costs through reduction in delay

Near-term	Mid-term: 2012-2018	Far-term: 2019+

Enhance Aircraft/ATM Information Exchange

ATM-001	Data Link Pre-departure Clearance Revisions	
OI-0321	Surface Management – Level 2 Data Link/Departures	
NIP	Enhanced Surface Traffic Operations	
ATM-002	Data Link En Route Clearance Delivery and Frequency Changes	
OI-0352	Automated Clearance Delivery and Frequency Changes	
		ATM-003 Data Link Taxi Instructions
		OI-0327 Surface Management – Level 3 Arrivals/Winter Operations/ Runway Configuration
		OI-0321 Surface Management – Level 2 Datalink/Departures
ATM-004	Data Link NAS Information and Advisories	
NIP	On-demand NAS Information	

Increase Access and Throughput at Non-Towered/Uncontrolled Airports

		ATM-005 Increase Access and Throughput at Non-Towered/Uncontrolled Airports
		OI-0313 Virtual Towers – Level 1 Sequencing, Separation, and Spacing
		OI-0315 Virtual Towers – Level 2 Sequencing, Separation, Spacing, and Surface Management

Reduce Weather Impacts through Improved Forecasting

ATM-006	Reduce Weather Impacts through Improved Forecasting	
OI-2020	Net-Enabled Common Weather Information – Level 1 Initial Capability	
OI-2021	Net-Enabled Common Weather Information – Level 2 Adaptive Control/Enhanced Forecast	
OI-2022	Net-Enabled Common Weather Information – Level 3 Full NextGen	

Capability	Key Enablers
ATM-001: Data Link Pre-departure Clearance Revisions – Airport operational efficiency is improved through the issuance of pre-departure clearance revisions through data link communications.	**Initial Data Link (FANS 1/A+,** FANS 2/B, ATN Baseline 1 LINK Post Pioneer**)**
ATM-002: Data Link En Route Clearance Delivery and Frequency Changes – ANSP workload is reduced, and operational efficiency in convective weather is improved, through the issuance of en route clearances and frequency changes via data link communications.	**Initial Data Link (FANS 1/A+,** FANS 2/B, ATN Baseline 1 LINK Post Pioneer**)**
ATM-003: Data Link Taxi Instructions – Efficiency of airport operations is further increased by the issuance—via data link communications—of taxi instructions to equipped aircraft.	*Data Link (Not supported by Initial Data Link Enablers)*
ATM-004: Data Link NAS Information and Advisories – Controller productivity is increased through the issuance of NAS information and advisories (e.g., textual weather, NOTAMs, departure sequences) via data communications.	**FIS-B, Initial Data Link (FANS 1/A+,** FANS 2/B, ATN Baseline 1 LINK Post Pioneer**)**
ATM-005: Increase Access and Throughput at Non-Towered/Uncontrolled Airports – ATM efficiency is improved through implementation of Staffed Virtual Towers Concept. Leverages data link communications for equipped aircraft.	*Data Link (Not supported by Initial Data Link Enablers)*
ATM-006: Reduce Weather Impacts through Improved Forecasting – Aircraft-based weather sensors and data-link communications allow integration of aircraft-sourced weather data into ATM decision making processes.	*Enhanced MDCRS Sensor, Data Link (Not supported by Initial Data Link Enablers), SWIM/COI*

FIRST PERSPECTIVES: WHAT DOES THE ROADMAP PROVIDE?

Work has been underway for many years to prepare for future aviation needs and challenges. Some of that work has been in development without specifically being associated with "NextGen." The challenge from the aircraft perspective has been to determine how these many different and sometimes similar activities relate to one another, and how much of the overall picture we understand. The other challenge is establishing and ensuring good communication between these multiple planning efforts to avoid duplication of work or inadvertent gaps.

The following points are noted with regard to what is emerging in terms of aircraft capabilities envisioned through the mid-term.

- Overall, the majority of aircraft capabilities through the mid-term have been previously identified with many in some form of planned development. The Roadmap illustrates the relationship between these activities. Future focus needs to be on identifying what capabilities are mature, what additional analysis or study is needed to finalize mid-term requirements, and how to integrate the activities for these capabilities with corresponding ground infrastructure and operator flight planning system changes.
- The work underway through the PBN Roadmap is foundational to NextGen. Nothing new has been identified in the Roadmap that would require the need for additional capabilities. However, there are elements where refinement in operational requirements (e.g., tighter performance requirements or differing air/ground system allocation) may require aircraft changes.
- A proposed framework for TBO has been provided to illustrate the need for tight integration of aircraft functional capability and performance. The complexity of the solution set will be determined by how enterprise services such as SWIM can work together with certified digital data link. This framework will change as other views are added; however, it does provide a significantly simplified view of how TBO operations can be conducted with known system functionality.
- A limited number of operational capabilities have been identified in the development of the Roadmap that were not associated with other known development activities. These represent gaps that will be further explored and developed in 2009. These include:
    - TCAS enhancements for higher density air operations and TBO (SAFE-004)
    - Aircraft-based capability for wake turbulence avoidance and mitigation (SAFE-007 & 008)
    - Improved traffic flow management with limited trajectory (NT-002 & 004)
    - ADS-B Separation (DS-009)

DEFERRED WORK

As noted previously, the Avionics Roadmap has used material from multiple sources to identify the operational capabilities needed for NextGen avionics and to correlate those with enabling avionics functionality. The objective has been to ensure that the NextGen plans reflect the recognition that aircraft capability will evolve over time, and to understand how the various change proposals work together to enable the needed capabilities as well as addressing any gaps that are identified.

Work captured in the JPDO ConOps and the IWP has placed very strong emphasis on a variety of avionics functionality being needed to support NextGen operations. In developing the first version of the Avionics Roadmap, a deliberate decision was made to limit the scope of work initially to that associated primarily with near- and mid-term implementation time frames (through 2018). Proposed changes involving avionics functionality that would not be implemented until the far-term time frame were largely deferred until 2009. The OIs listed in Appendix 3 reflect those that are considered to have aircraft relevance that will be examined in 2009, but were not included in this Roadmap either because of the far-term time frame consideration, or because they involved aircraft changes in areas other than avionics.

FUTURE WORK

It is recognized that more work is needed to expand the breadth and depth of information in this Avionics Roadmap. It is also recognized that this information needs to be incorporated into other permanent NextGen planning documents as they are revised. Considering these needs, the JPDO Aircraft WG will focus on the following actions in 2009:

1. Mature the content for all six Capability Groups and corresponding enablers presented in the Roadmap through the far-term time frame (2019 to 2025). Considerable focus will be placed on TBO operations and how this advances the understanding of flight management system (FMS) functions and data communication functions.
2. Incorporate more detailed descriptions of the capabilities and functional performance suitable for airframe and avionics manufacturers and operators to start developing system designs, integration plans, and product development proposals.
3. Outreaches—within JPDO, with agencies and with industry groups and representatives—to identify how the Aircraft WG can lead or assist in advancing the work needed for pursuing these aircraft capabilities. It is recognized that great work is underway in many forums and it is desired to identify how the Avionics Roadmap and the Aircraft WG can further those efforts and not duplicate them. Priority will be given to each of the capabilities noted in Appendix 4 that were assessed as having greater potential to solve problems in the NAS based on the initial assessment of benefit and risk. This recognizes that multiple views need to be considered in developing the right plans for NextGen—the Avionics Roadmap provides an initial aircraft perspective and other perspectives need to be integrated to support future planning and decision making.
4. Address the needs of the broader user community—GA, Military, and UASs—and the types of aircraft capabilities envisioned for their participation in NextGen. These considerations will be reflected in planned revisions to the Avionics Roadmap. A workshop in early 2009 is being considered to facilitate broader industry input in this regard.
5. Address the aircraft-related OIs noted in Appendix 3 with regard to how they should be incorporated into this Roadmap or addressed through other actions.
6. Work with the JPDO's Interagency Portfolio and System Analysis Division to refine benefits, risk, and costs assessments associated with the content captured in this Roadmap. Use this information to guide future work and ultimately to confirm the right set of aircraft capabilities and avionics enablers have been identified.
7. Identify how information from the Avionics Roadmap should be incorporated into other NextGen planning documents when they are revised.

In support of better understanding the capabilities illustrated in this Roadmap and to better plan future work on how to mature these capabilities, an initial assessment was performed examining the benefits and risks associated with each. Further details on this work are provided in Appendix 4. This assessment was based on existing data and did not consider cost or broader implications (e.g., ground system infrastructure investments, potential conflicts with capabilities that may emerge in the far term or in consideration of other industry and agency commitments). This assessment, while limited in scope, reflects a valuable first step in helping the Aircraft WG identify where greater priority should be given in terms of interfacing with other groups and activities, both within and outside of JPDO. It is also recognized that other data sources likely exist that have relevance to the capabilities reflected in this Roadmap beyond what was readily available to support this first assessment.

Closing

Version 1.0 of the Avionics Roadmap focused on aircraft and avionics capabilities through the mid-term (2018) and air carrier, high-end business aircraft operations. Version 2.0 will address far-term capabilities and requirements, the needs of the other user communities and provide airframe and avionics manufacturers and operators the details needed to begin the necessary planning, development, and implementation of the equipment needed to enable future NextGen capabilities.

NextGen Avionics Roadmap

Document Revision History

VERSION	DATE	DESCRIPTION
	August 2007	Direction provided by Charlie Leader following discussions with NextGen IMC to develop and Avionics Roadmap
Conceptual	January 15, 2008	Framework and approach briefed to the NextGen Institute Management Council
Conceptual	February 6, 2008	Framework and approach briefed to the JPDO Integration Council
Preliminary	May 14, 2008	Progress briefing and discussion on Roadmap capabilities structure with Jay Merkle, JPDO Chief Architect, Edgar Waggoner, Interagency Architecture and Engineering Division Director and Robert Pearce, JPDO Deputy Director, et. al.
Draft Version 0.65	July 10, 2008	Complete draft version of Roadmap provided to Ed Waggoner to illustrate progress and in advance of request to all work groups for comments
Draft Version 0.65	July 28, 2008	Transmitted to the JPDO Working Group Co-Chairs with request for input by August 15; document revised based on comments received from ANS, Safety, Security and Global.
	October 1, 2008	Progress brief for IC with acknowledgement to complete Roadmap in October 2008
Draft Version X.X	October 16, 2008	Transmitted and briefed to the NextGen Institute Management Council
Version 1.0	October 24, 2008	Transmitted to the JPDO Working Group Co-Chairs and the Aircraft Working Group Members
Version 1.0	November 13, 2008	Published on the JPDO Web Site
Version 1.0		Formally transmitted to agencies and NextGen IMC

*Revision History written by Jeff Duven, Government Co-Chair of the Aircraft Working Group

Appendix 1: Trajectory-Based Operations Framework

An important gap in the Next Generation Air Transportation System (NextGen) Concept of Operations has been lack of specificity for Trajectory-Based Operations (TBO), particularly in the area of definition for a four-dimensional trajectory (4DT) and how TBO depends upon and utilizes the 4DT. This appendix proposes a definition of the elements of a 4DT, and will attempt to provide insight into how TBO would manipulate/utilize the 4DT to manage the airspace. As the capabilities sections of this Roadmap illustrate, TBO between air and ground can be used across a range of levels of capability. All of these levels can fit within a TBO framework where 4D representations of flight trajectories are used for implementing air traffic management (ATM).

HIGHLIGHTS OF THIS CONCEPTUAL TBO FRAMEWORK ARE:

1. Mixed capability TBOs form an inclusionary basis for ATM everywhere in the National Airspace System (NAS). It is inclusionary because performance levels and functional capability requirements for specific times and routes are set by ATM based on demand, and the system is able to handle aircraft of mixed capability levels everywhere. As performance requirements tighten at times, lower performers may have reduced access, but only for those times.

2. All aircraft have an associated 4DT, whether completely or partially generated on the aircraft and data-linked with the ground systems using or completing the 4DT, or generated from a flight plan filed by voice and turned into a 4DT by ground systems. This allows for mixed capability operations where aircraft of differing capability can be managed in the same way throughout the NAS by service providers who have a single mode of operation (TBO) for all aircraft. It is key that ATM systems are the repository for all trajectories, and that all trajectories are 4DT with varying levels of performance required based upon capacity driven need and aircraft capability.

3. The transition to 4DT starts with improvements to ATM systems that support a 4DT concept of operations and take advantage of the data communications capability in some existing aircraft. ATM systems should accommodate a heterogeneous aircraft capability in the same operational concept and with the same tools, wherever possible, to enable early benefits and to allow the airborne system evolution to proceed independently, driven primarily by the operator's need for access and flexibility.

4. While a 4DT is negotiated and set prior to flight, ATM tools set the required performance (in all four dimensions), windows (as needed) within which trajectories may be placed (all four dimensions), and constraints (as needed) where trajectories may not be placed. Windows can collapse to points, i.e., an altitude window can become a hard altitude constraint, if there is no flexibility left in accommodating traffic demand. These are the primary parameters that need to be exchanged between aircraft and air navigation service provider (ANSP) systems. Trajectories are moved as necessary through rerouting (modifying the trajectory points), shifting of windows, or modifying constraints.

5. ATM clearances that modify trajectories for managing the traffic may be voice or data, depending on the aircraft and operation, with the performance level associated with each trajectory known by the ground systems and handled accordingly. Data allows more complex clearance and revisions, and voice provides an exception mode and simpler services to unequipped aircraft. Clearances may add or modify windows, may set required performance levels or constraints for a 4DT, or provide revisions to the routing of the intended trajectory.

EVOLVING AIR TRAFFIC OPERATIONS

TBOs provide a framework within which integrated planning, decision making, negotiations, and execution of operations may be performed based upon variable demand and performance capabilities forming a total system concept. In this total system, the use of ground-based tools, aircraft decision support tools, planning and processes, and human interfaces are all integrated to optimize the operational solution. TBO with performance attributes has been embraced as a central theme of both the NextGen and Single European Sky ATM Research Programme (SESAR)

Concepts of Operations. But what is TBO, how will it be used, and how can we transition from current operations to this future capability? In answer to these questions, the following material is presented as a conceptual framework for unifying the representation of different alternative elements within the NextGen concepts, while also allowing for the transition stages along the way.

CONCEPT OF OPERATIONS

The fundamental requirement of NextGen is to safely accommodate significantly increased traffic, and to do this in airspace that is already congested, such as between heavily traveled city pairs (e.g., Washington and Chicago) and near the busiest airports. It is also advantageous to the flow of traffic to attempt to manage all traffic in similar ways, homogeneously handling all aircraft by trajectory with varying levels of capability and dynamically setting the required capability in response to changing situations and density needs. This requirement leads to a transformation of the national airspace to TBO in which precise management of an aircraft's current and future position enables increases in throughput and improvements in efficiency when necessary by varying the level of performance required to meet the need. All airspace operations are based upon trajectory and are inclusive of all capability levels of aircraft with flexibility inherent in the trajectory clearance that sets the performance required at that time, and allows for the aircraft to optimize performance within some bounds or allows the aircraft some maneuverability to resolve delegated separation to other aircraft.

In the following sections we will expand upon this concept of operations, and will propose in more detail the elements of a 4DT and their uses in the phases of operation.

PHASES OF TRAJECTORY OPERATION

Having discussed the high-level concept of TBO, we will attempt to describe a possible phased method of operation under TBO, with a more detailed possible definition for 4DT to follow. There could be four phases to TBO: prenegotiation, negotiation, agreement, and execution.

Prenegotiation: As described in the operational concept, all trajectories in the airspace and on the airport must satisfy a set of constraints. Constraints are not unique to a single trajectory; they apply to the system itself. A thunderstorm can impose a constraint where access to certain airspace is not available, and forecast storms can impose constraints on traffic densities to build in sufficient maneuverability. Other constraints may be defined based on limited airport capacity. From the aircraft operator's perspective, the prenegotiation phase involves the definition of the trajectory objectives: where do I want to fly, when do I want to fly, and how would I like to get there? Aircraft constraints are also defined during this phase, such as limits on the types of approach operations that can be flown.

Negotiation Phase: During the negotiation phase, operators use all available information to determine their trajectory objectives and negotiate that with the ANSP to determine if it is feasible. The operator may accomplish this through flight planning (prior to departure), aircraft systems while in flight, or through a flight operations center. Similarly, the ANSPs use all available information to determine the trajectories that make the most efficient use of available airspace and negotiate with the operator.

The operator and the ANSP need to consider current and forecast weather, any special use or otherwise restricted airspace, and any other aspects that may restrict the achievable trajectory (e.g., availability of navigation aids suitable to support the operation). The successful completion of the negotiation phase is the agreement phase. Note that the negotiation phase can also be entered due to unanticipated changes during the execution phase. For negotiation that occurs during in-flight operation, there is a requirement for timely completion of the negotiation phase. In the limit, during operations where immediate action is required by the controller to assure safe separation is maintained, the negotiation phase may be skipped and proceed immediately to the agreement phase.

Agreement Phase: The agreement phase is very brief, and consists of the request and acceptance of a trajectory clearance. Trajectory clearances will set the window and performance requirements for all four dimensions, although they may not be addressed simultaneously (as is the case with future

operations and change in altitude along a route). The intended trajectory is not included in the agreement phase, other than the degree to which it is constrained by the trajectory windows. Any validation of the trajectory that is needed to commit to the trajectory, for the operator or the ANSP, is accomplished as part of this phase. For example, when the ANSP grants a clearance request the ground automation system must provide some assurance that the aircraft can operate along the trajectory without interference, provided there are no unanticipated changes in the environment (e.g., weather, traffic). An unsuccessful agreement phase returns the trajectory to the negotiation phase, while a successful agreement phase leads to the execution phase. Note that an actual clearance may only affect a portion of the trajectory at a time, such as a change in assigned altitude.

Execution Phase: During the execution phase, the aircraft maintains a trajectory within the window defined in the clearance, and with performance that satisfies the performance requirement of the agreement. In the far-term with full 4DTs, the trajectories are designed during the negotiation phase to both satisfy the demand on the system from scheduled and unscheduled traffic and events, and to minimize interaction and changes during the execution phase. The aircraft will monitor compliance with the agreement (as will the separation function of ANS), and if, for any reason, the aircraft can no longer comply with the clearance then it must be alerted and renegotiated. Ideally this would occur prior to actually changing the trajectory. However, where immediate action is required by the aircraft to assure safe separation is maintained (e.g., Traffic Alert Collision Avoidance System resolution advisory), the trajectory change is made prior to renegotiation. It may also be necessary for the ANSP to renegotiate the clearance. This may arise due to unanticipated changes in weather, failures of aircraft equipment or supporting ANSP infrastructure, or as a result of changes in the trajectories of other aircraft.

RELATIONSHIP TO CONOPS ATM TBO FUNCTIONS

The phases of trajectory operation can be related to the ATM functions that have been identified for TBO, and are being developed within the Air Navigation Services Working Group (WG) of the Joint Planning and Development Office. As the definitions of those functions are refined, the relationship between the aircraft perspective described here and the ATM perspective will be elaborated.

TBO AND DELEGATED SEPARATION

Safe separation between actual trajectories must be maintained during the execution phase of all trajectories. The responsibility for monitoring that separation is maintained during any phase can lie with the controller (e.g., IMC operations) or the flight crew (e.g., VFR operations). Where separation is the responsibility of the controller and is reflected in the trajectory clearance of the aircraft involved. Achieving optimal spacing may involve applying tight window constraints to the trajectories, and renegotiation of the trajectory as improved information becomes available (weather or the actual trajectories of aircraft). In contrast, where separation responsibility is delegated to the flight crew, the flight crew must have some flexibility in their trajectory clearance that enables them to maintain the required separation without renegotiation with the ANSP. As such, larger window constraints are required. This affords greater flexibility to the aircraft at a tactical level, and relaxes certain aspects of the aircraft performance requirements such as the flight technical error, while demanding greater performance from other aspects of the system such as ADS-B. The tradeoffs between these separation concepts will need to be further evaluated to determine the best allocation of requirements between the aircraft and ground systems.

TBO AND INFORMATION EXCHANGE

In order to improve efficiency, it is critical to provide access to high-quality information during all phases of planning and execution including the negotiation phase. This includes access to system-wide constraints such as: forecast and tactical weather, airspace, aircraft performance, traffic, and environmental. For this phase, there is a need for net-centric communications whereby all available data that affects the planning is available to all constituents. This data is planned to be hosted in a way where data can be requested from any authorized user within the network. For aircraft operators, they may choose to rely primarily on their flight operations center (FOC) to access this

data and negotiate the trajectory, or may provide access from the flight deck and empower the flight crew to negotiate this trajectory. The allocation of this function between the aircraft, ANSP, and the Airline Operational Control is another key consideration in defining the future aircraft. In order to optimize the execution of the trajectory, information needs to be presented in a consistent way that is both timely and accurate. Each of the constraints described will be processed by decision support tools that will reside either within the ground automation or on-board systems. To allow this information to be consumed seamlessly, each of the constraints will need to be represented in a consistent format. This will allow airspace, traffic, terrain, weather, obstacles, and other system limitations to be communicated effectively throughout the system. To manage costs for implementation, the information elements need to have performance parameters assigned based on how that information will be used and the effect of the decision made from that information. Information performance will be used to determine which of the available connectivity methods will be appropriate for delivery and confirmation. Different technologies may be chosen for ground-ground and air-ground exchanges of information depending on whether the information is being used for planning, negotiations, or trajectory execution and monitoring. In this framework, the certified data link system would be required for support of the TBO agreement phase, while other technologies, such as SWIM, could support both the prenegotiation and negotiation phases. This is consistent with the overall performance-based operational nature of the system. It allows the communications assets to be flexible and scalable based on the necessary performance for the intended operation.

THE 4DT OBJECT DEFINED

The trajectory describes the path of the aircraft through four dimensions: lateral (latitude/longitude), vertical (altitude), and time. While the *actual* trajectory is uniquely known after it is flown, there is always some uncertainty with respect to the aircraft execution of the *intended* trajectory. The trajectory object should consist of a set of parameters that completely describe the intended trajectory. The following elements could be considered to be components of that object:

Trajectory objectives: The objectives (like the SESAR concept of "business trajectory") should contain information describing the aircraft operator's objectives for a particular flight. A conventional IFR flight plan is an example; it describes where the operator wants to go, when they want to go, and their preferred route (a route is not a continuous set of trajectory points, it is a discrete representation of a full trajectory).

Intended trajectory: The continuous trajectory that the operator intends to take, and would take if there were no errors or uncertainty in executing the flight. For example, a repeatable and predictable definition of the lateral aspect of a trajectory was developed as part of Required Navigation Performance Area Navigation (RNP-RNAV). It was defined in RTCA/DO-236 as the desired trajectory, but referred to in a general context as the intended trajectory to clearly distinguish it from the trajectory objectives.

Actual trajectory: The aircraft trajectory that is actually flown. The actual trajectory can differ from the intended trajectory due to errors in the control loop: e.g., in the estimated position of the aircraft, in the definition of the intended trajectory, and in residual control error (i.e., flight technical error in the lateral and vertical dimensions). The actual trajectory only exists behind the aircraft, up to the current aircraft position and velocity.

Window: A conceptual extension of the common example from current operations, the vertical trajectory during an altitude transition. In this case, the controller can assign a new en route altitude for the aircraft to descend to, but the specific path to be taken by the aircraft (the rate of descent) is frequently undefined. By extension, there could be an allowable region (in any dimension), within which the ANSP will allow the aircraft to relocate or revise its intended trajectory subject to the limits of its required performance (the aircraft is assumed to be complying with the requirement). While it would be initially specified relative to the intended trajectory, once defined it would become fixed in space/time. In many cases, there may be no flexibility in the intended trajectory and the window would have to collapse to be identical to the intended trajectory itself. This window has also been

referred to as a flexibility volume, emphasizing that it has multiple dimensions and describes the trajectory flexibility that is granted to an aircraft.

Performance: There would be performance requirements that describe how closely the aircraft's actual trajectory must adhere to the intended trajectory, extensions from the lateral performance requirement that are captured in the RNP designation, which indicates accuracy and integrity requirements. The performance requirements must address the total system error between the actual trajectory and the intended trajectory. These performance requirements would be levied by ANSP as part of the trajectory, whether static or dynamic. However, there is another aspect of performance, and that is achieved performance, as estimated by the aircraft and used to assure compliance with the ANSP required performance (e.g., ANP vs. RNP alerting for RNP operations). As in the RNP concept, the tool available to ANSP could be the required performance, with the aircraft having the responsibility to comply or advise. This would free ANSP from estimating aircraft performance aside from having knowledge of the best levels that may be available for use in a dynamic situation.

In order to define a complete trajectory object, it would be defined in all four dimensions. It would consist of lists of parameters (such as a series of latitudes and longitudes to identify a fix in the plan, or altitudes to identify constraints) and common algorithms (e.g., connecting fixes by geodesic paths) to construct the complete, continuous trajectory. In addition, the required performance level in each dimension would be defined to allow the ATM trajectory management and separation management to perform their functions, and for the airborne system to know whether or not it can comply. The performance would be specified as necessary to maintain efficiency and capacity – strict trajectory compliance is not necessarily implied.

Table 1-1 provides examples of trajectory characteristics that are in use in current operations within the NAS:

Table 1-1. Trajectory Characteristics Addressed in Current Operations

	Intended Trajectory	Window	Performance
Lateral (2D)	Leg Types (Track-to-Fix, Radius-to-fix)	Leg Types (no flexibility), fly-by turn transition area, holding patterns	RNP designation
Vertical	Assigned altitudes, descent rates, approach glidepath	Assigned altitudes (no flexibility), minimum en route altitude, at-or-above altitudes, at-or-below altitudes, altitude windows	Implicit (e.g., certification and operational requirements for barometric altimetry)
Time (along path)	Speed assignment	Speed assignment (no flexibility), speed restrictions	Implicit

In typical current operations, the concept of a changeable lateral window is not defined or in use. The window for the lateral path is simply the intended lateral trajectory itself, as current separation is accomplished primarily in the lateral dimension using current-time information for same-level traffic. It is natural that the dimension that is most constrained is that which is graphically displayed to the controller and used as one of the means of achieving safe separation. One exception is the fact that a lateral window in current operations may be found in the lateral fly-by transition, where a window of airspace is reserved around the turn point to allow for a variation of path location relative to the transition waypoint due to speeds or other constraints of the aircraft systems. This window is collapsed to zero through the use of the RF transition in RNP operations. An example of a vertical window might be an assigned altitude change, assigned tactically, or a "between" altitude constraint defined in association with a published route or procedure. Of all the dimensions, time is currently the least constrained; it is addressed only through speed assignment to maintain separation

tactically, propagating the current aircraft position in lateral dimension forward for a short period of time.

As these concepts are evolved, separation might become more strategic, using the intended trajectories to avoid conflicts between aircraft, and it could become more integrated across all dimensions. It is important to challenge our conventional notions of how these trajectories are managed. First, adjustment of trajectory parameters to address system demand (paths, windows, performance required) could apply to the full trajectory from origin to destination. This is because some aircraft will be actively controlling to the known and negotiated intended trajectory over its full length, compensating for disturbances to remain within its windows and performance bounds. For those aircraft that cannot control to the intended trajectory, larger tolerances for prediction and less stringent requirements will be used. The control aspect of the negotiated trajectory extends the time horizon of predictability for aircraft that actively control to it within definable tolerance all the way to the destination airport in current FMS equipped airplanes; this method will equally apply to lesser equipped aircraft, but the available performance limits will not be as high. If and when upsets like weather occur, the trajectories could be moved through a process of renegotiation where, once complete, the time horizon of predictability might again be the destination.

Within NextGen, lateral trajectory windows could have utility for unmanned aircraft or as a means of accommodating special use airspace (which is a lateral window for the operations being conducted therein). They also would have utility to provide flexibility for aircraft to divert around convective weather, or to enable path contraction or expansion as a means of ensuring better time-of-arrival control at a merging point. Lateral trajectory windows can be a valuable tool to ANSP. If they are geographically specified, they could be moved to avoid constraints such as weather, with the trajectory redefined within the relocated window. They could also be reduced in size at the same time if necessary to allow for higher density of operations

Similarly, the time dimension could use more explicit definition. It is commonly recognized that a required time of arrival at the final traffic merge point (e.g., approach intercept or the runway threshold) could be an important part of improving the sequencing of arrival flows during near-capacity operations. However, the ETAs of a negotiated trajectory could be as effective in merging and sequencing provided that they are accurate. If accurate ETA information from highly equipped aircraft is available, they could be analyzed relative to each other at common points (merges) or on common paths (spacing) to handle multiple aircraft. In the event some ETAs do not allow for the planned operation, assignment of an RTA could be used to resolve the issue as a last resort.

When all four dimensions are considered, the relationship between the types windows becomes more apparent. If the lateral and vertical windows are completely constrained, the time of arrival of any crossing traffic must also be completely constrained in order to maintain separation. An analogy can be found in automobile traffic, where the lateral path is constrained by the roads and traffic lights control crossing times where roads intersect. However, if flexibility is given in at least two dimensions, it may be possible to maintain more efficient traffic flows by allowing each aircraft some flexibility to account for changes in the airspace, the weather, or other traffic. This is commonly accomplished in today's operations through the flexibility of vertical (altitude assignment) and time (speed assignment). Within NextGen, flexibility in the lateral dimension should also be considered in the same way that two cars driving across a parking lot can avoid each other with minor changes in their path and without altering their speed. The complete trajectory object for NextGen must be defined in the near-term, as it can affect multiple aircraft systems and ANSP systems. Key attributes that need to be addressed include:

1. Lateral windows: These are not currently defined with the exception of holding patterns and fly-by and fly-over turns.
2. Vertical desired trajectories: Currently, vertical trajectories are defined only by an Air Traffic altitude constraint to an Air Traffic altitude constraint, or by a flight path angle into a fix. Additional paths may be necessary depending on the required tolerances, such as the curved paths associated with idle descent and barometric vertical navigation.

3. <u>Vertical performance</u>: Vertical RNP, to include altimetry errors as well as flight technical errors, would need to be developed. Vertical separation criteria between two aircraft in transition would also need to be studied and developed.
4. <u>Time</u>: All three characteristics of time (trajectory, window, and performance) need to be developed.

While all achieved aircraft trajectories are in fact continuous (e.g., from departure gate to arrival gate), the trajectory object may only contain specific elements of the trajectory, with ground and airborne automation systems computing a continuous intent trajectory by using identical methods to fill the gaps. While the actual trajectory is only defined behind the aircraft, the intended trajectory is only useful in front of the aircraft, and a trajectory clearance may only cover a portion of the remaining flight. The trajectory object is a subset of the flight object, which will include all data associated with a particular flight within the ground automation systems.

Appendix 2: Key Enablers

Each operational capability presented in this Roadmap is associated with one or more change that enables it. In this appendix, the key enablers are examined, with each key enabler denoting the operational capabilities it supports. As the Roadmap has begun to establish the needed equipage, this appendix, at a high level, answers the question: what operational capabilities are associated with each key enabler? The key enablers are then described in terms of technology options to support that aircraft functionality. This allows a simple technical readiness review (red/yellow/green) expressed in terms of a stoplight chart. The notes section of the appendix recognizes future and emerging technology options. This allows both a gap analysis of Roadmap readiness, and a pointer to further standards and research and development work.

Future versions of the Avionics Roadmap will address expected performance levels for the various enablers, if they are not already specified or if changes to existing specifications are needed. This will, for example, require the specification of the level of functionality for the various operational capabilities that are enabled by Automatic Dependent Surveillance-Broadcast (ADS-B) In. This specification of avionics performance level will require performance allocation for each operational capability between the aircraft, air traffic, and Airline Operational Control elements. This allocation will be captured in this document and used to revise other NextGen planning documents.

It is also important to note that the Avionics Roadmap does not convey how certain changes (enablers) would be implemented (voluntary action, incentives, mandates, or other means). It is recognized that the Federal Aviation Administration (FAA) is in the midst of proposed rulemaking for ADS-B Out and this Roadmap specifically recognizes the operational capabilities that both ADS-B Out and ADS-B In can support. Future versions of this Roadmap will reflect FAA decisions regarding required ADS-B Out functionality and any impacts that these decisions may have on the aircraft operational capabilities presented in this document.

The Aircraft Working Group invites comment on this work, especially in the area of functional allocation. As we look at the Roadmap, are there other simpler ways to accomplish the required operations? How should this functionality be allocated?

Table 2-1. Technology Options for Positioning Key Enablers (Mid-Term)

Key Enabler Operational Capabilities	Technology Options to Achieve Key Enabler Aircraft Functionality (Green = Available; Yellow = Under Development; Red = Not Yet Defined or Not In Development for Use)	Future/Emerging Technology Options/ Notes
GNSS SAFE-007 SAFE-008 LV-004	For Technical Standard Order (TSO) C129: GNSS source for FMS / or / Stand-alone GNSS receiver/navigator For TSO-C145/146: GNSS source for FMS / or / Stand-alone GNSS receiver/navigator	Future technology options may include: GBAS I, GBAS III, GRAS, GPS L5, GLONASS, Galileo

Table 2-2. Technology Options for Communications Key Enablers (Mid-Term)

Key Enabler Operational Capability	Technology Options to Achieve Key Enabler Aircraft Functionality (Green = Available; <u>Yellow</u> = Under Development; *Red* = Not Yet Defined or Not In Development for Use)	Future/Emerging Technology Options/ Notes
Initial Data Link (FANS 1/A+) SAFE-002 SAFE-006 PRP-006 NT-001 NT-002 NT-004 NT-005 NT-006 NT-007 DS-002 ATM-001 ATM-002 ATM-004	Oceanic & Accommodated Domestic • Oceanic: RTCA Document (DO)-306 / DO-258A • Domestic: DO-290/2 / DO-305 Components involved: • Cockpit display (HMI) • FMS (application hosting) • CMU (routing) • Oceanic: VHF / SATCOM (subnet) • Domestic: VDR (subnet)	Forward fit to migrate to FANS 2/B; current fleet to be accommodated.
Initial Data Link (FANS 2/B) SAFE-002 SAFE-006 NT-002 NT-004 NT-005 NT-006 DS-002 ATM-001 ATM-002 ATM-004	Domestic Data Link with no limitations • DO-290/2 / DO-280B Components involved: • Cockpit display (HMI) • FMS (application hosting) • CMU (routing and application hosting) • Oceanic: ACARS / SATCOM (subnet) • Domestic: VDR (subnet)	Current fleet to migrate to LINK Post Pioneer ATN Baseline 1 upon European Union implementing rule target date

Key Enabler Operational Capability	Technology Options to Achieve Key Enabler Aircraft Functionality (Green = Available; Yellow = Under Development; Red = Not Yet Defined or Not In Development for Use)	Future/Emerging Technology Options/ Notes
Initial Data Link (ATN Baseline 1 LINK Post Pioneer) SAFE-002 SAFE-006 NT-002 NT-004 NT-005 ATM-001 ATM-002 ATM-004	Domestic Data Link with no limitations • DO-290/2 / DO-280B Components involved: • Cockpit display (HMI) • CMU (application hosting & routing) • FMS (Integration or application hosting) • VDR (subnet)	Forward fit to migrate to Initial ICAO Compliant CPDLC or Extensions to ARINC 623
Data Link (Integrated with FMS or stand-alone navigator, and not supported by Initial Data Link enablers) PRP-004 PRP-005	RTCA Special Committee (SC)-214	Presumes integration with FMS or stand-alone navigator. Not supported by initial CMU-based enablers.
Data Link (Not Supported by Initial Data Link Enablers) SAFE-002 SAFE-007 NT-008 NT-009 ATM-003 ATM-005 ATM-006	SC-214	

Key Enabler Operational Capability	Technology Options to Achieve Key Enabler Aircraft Functionality (Green = Available; Yellow = Under Development; Red = Not Yet Defined or Not In Development for Use)	Future/Emerging Technology Options/ Notes
ADS-C PRP-006	Oceanic & Accommodated Domestic • Oceanic: DO-306 / DO-258A • Domestic: DO-290/2 / DO-305 Components involved: • Cockpit display (HMI) • FMS (application hosting and integration) • CMU (routing and application hosting) • Oceanic: VHF / SATCOM (subnet) Domestic: VDR (subnet)	Forward fit to migrate to Converged FANS / ATN ADS-C; current fleet to be accommodated.

Table 2-3. Technology Options for Surveillance Key Enablers (Mid-Term)

Key Enabler Operational Capability	Technology Options to Achieve Key Enabler Aircraft Functionality (Green = Available; Yellow = Under Development; Red = Not Yet Defined or Not In Development for Use)	Future/Emerging Technology Options/ Notes
ADS-B Out PRP-007 DS-008 DS-009 NT-003	UAT Or 1090ES Out	ADS-B NPRM proposes ADS-B Out mandate based on airspace classification and 1090ES ADS-B Out mandate for FL240 and above

Table 2-4. Technology Options for Trajectory Management Key Enablers (Mid-Term)

Key Enabler Operational Capability	Technology Options to Achieve Key Enabler Aircraft Functionality (Green = Available; Yellow = Under Development; Red = Not Yet Defined or Not In Development for Use)	Future/Emerging Technology Options Notes
RNAV PRP-002 PRP-003 NT-001 NT-002 NT-004 DS-001 DS-002	FMS with RNAV Input (as required) Or Stand-alone GNSS receiver/navigator with RNAV (As required)	RNAV 1 for terminal operations; RNAV 2 for en route operations
RNP SAFE-001 PRP-001 PRP-003 PRP-004 PRP-005 DS-006	Position Source for FMS with RNP as Required by Procedure / OR / Stand-alone GNSS receiver/navigator with RNP as required by procedure	As required by procedure
RNP 10	Position Input to FMS as required / OR / Stand-alone GNSS C129 Navigator	
RNP 4 PRP-006	Position Input to FMS as required / OR / Stand-alone GNSS C129 Navigator	
RNP 1	Position Source for FMS as required / OR / Stand-alone GNSS receiver/navigator with RNP 1	
RNP 0.3	Position Source for FMS as required / OR / Stand-alone GNSS receiver/navigator with RNP 0.3	Capability to fly procedures with RF Legs
RNP-2	Position Source for FMS with RNP-2 / OR / Stand-alone GNSS receiver/navigator with RNP-2	See AC 90-RNP

Key Enabler Operational Capability	Technology Options to Achieve Key Enabler Aircraft Functionality (Green = Available; Yellow = Under Development; Red = Not Yet Defined or Not In Development for Use)	Future/Emerging Technology Options Notes
RNP SAAAR PRP-001 DS-006 DS-007 DS-010 LV-001 LV-002	Position Source for FMS with RNP SAAAR authorization for aircraft and aircrew	
RF Leg Capability PRP-001	FMS w/ RF Leg Capability as Required by Procedure / OR / GNSS Navigator with RF Leg Capability as Required by Procedure	
VNAV PRP-004 PRP-005	Baro or Geometric Capable FMS / OR / GNSS Stand-alone Navigator	Advisory vs. coupled VNAV
Vertically guided RNP PRP-005	TBD	
CTA NT-005 NT-006 NT-007	CTA-capable FMS / OR / CTA-capable stand-alone GPS navigator	
D-Taxi	TBD	Integration with data link and other systems not defined

Table 2-5. Technology Options for Displays Key Enablers (Mid-Term)

Key Enabler Operational Capability	Technology Options to Achieve Key Enabler Aircraft Functionality (Green = Available; Yellow = Under Development; Red = Not Yet Defined or Not In Development for Use)	Future/Emerging Technology Options Notes
CDTI SAFE-005 PRP-006 DS-001 DS-002 DS-003 DS-004 DS-005 DS-006 DS-007 DS-008 DS-009 DS-010 LV-003 LV-004	Class 2 or Class 3 EFB / OR / EFIS-Based CDTI / OR / Stand-alone MFD with CDTI	Application-specific (e.g., no airborne ADS-B apps on Class 2 EFB)
CDTI with Alerting SAFE-005	TBD	
Guidance Display DS-009	TBD	
Moving Map SAFE-002 SAFE-003 SAFE-005	Class 2 or Class 3 EFB / OR / EFIS-Based MFD / OR / Stand-alone MFD	
EFVS LV-001 LV-002 LV-003 LV-004	EFVS system with operational credit	
SVS LV-001 LV-002 LV-003 LV-004	SVS system with operational credit	

Table 2-6. Technology Options for Safety Enhancements Key Enablers (Mid-Term)

Key Enabler Operational Capability	Technology Options to Achieve Key Enabler Aircraft Functionality (Green = Available; Yellow = Under Development; Red = Not Yet Defined or Not In Development for Use)	Future/Emerging Technology Options Notes
Aircraft Characteristic Database SAFE-007 SAFE-008	TBD	
Aircraft Wake Database SAFE-007 SAFE-008	TBD	
FIS-B SAFE-002 SAFE-006 PRP-006 ATM-004	UAT-based FIS-B / OR / Satellite-Based FIS / AND / Moving Map/Multi-Function Display with Available Positioning Source	
TAWS Enhancements SAFE-001	TBD	
TCAS Enhancements SAFE-004	TBD	
Enhanced MDCRS Sensors ATM-006	TBD	
Improved Terrain Database SAFE-001 SAFE-003	TBD	
Improved Obstacle Database SAFE-003	TBD	

Key Enabler Operational Capability	Technology Options to Achieve Key Enabler Aircraft Functionality (Green = Available; Yellow = Under Development; Red = Not Yet Defined or Not In Development for Use)	Future/Emerging Technology Options Notes
SWIM/COI ATM-006	TBD	
Wake Decay Model SAFE-007	TBD	
Wake Transport Model SAFE-007 SAFE-008	TBD	
GLS III LV-001 LV-002	TBD	

Appendix 3: Deferred Integrated Work Plan Operational Improvements

Some operational improvements (OIs) enabled by changes to aircraft are proposed by the Joint Planning and Development Office Integrated Work Plan (IWP) and are omitted from this Roadmap. In some cases, no assessment has been made because it is either beyond the scope (avionics for air traffic management and safety through the mid-term) of this initial version of the Avionics Roadmap, or because insufficient information on the concept was available from the IWP to enable evaluation. The following table summarizes these deferred OI and the reasons for deferral.

IWP OI #	Title	Reason for Deferral
OI-0340	Near-Zero-Visibility Surface Operations	Concept as defined in IWP was insufficiently mature for evaluation
OI-0341	Limited Simultaneous Runway Occupancy	Concept as defined in IWP was insufficiently mature for evaluation
OI-0354	Reduced Oceanic Separation – Co-Altitude Pair-wise Maneuvers	Concept as defined in IWP was insufficiently mature for evaluation
OI-0362	Self-Separation - Self-Separation Airspace	Concept as defined in IWP was insufficiently mature for evaluation
OI-0364	Improved Airframes to Reduce Wake Generation	Not Avionics
OI-2030	Weather Mitigation - Aircraft Systems	Out of initial scope (not ATM-related Avionics)
OI-3000	Increased Crash Survivability - Energy Absorbing Structures	Not Avionics
OI-3001	Increased Crash Survivability - Fire Prevention and Suppression	Not Avionics
OI-3002	Improved Aircraft Upset Prevention and Recovery	Out of initial scope (not ATM-related Avionics)
OI-3008	Reduced Human Errors in Nominal and Off-nominal Conditions	Out of initial scope (not ATM-related Avionics)
OI-3009	Reduced Component Failures	Out of initial scope (not ATM-related Avionics)
OI-3011	Reduced Human Errors in Operation of Automated Systems – Level 1	Out of initial scope (not ATM-related Avionics)
OI-3012	Reduced Weather-Related Incidents – Level 1	Out of initial scope (not ATM-related Avionics)
OI-3013	Reduce Airborne Icing-related Incidents – Level 1	Out of initial scope (not ATM-related Avionics)
OI-4512	Improved Restricted Airspace Planning/Management - Level 3 Flight Risk	Unclear aircraft role and equipage
OI-4600	Reduced Threat of Aircraft and UAS Destruction or used as a Weapon	Out of initial scope (not ATM-related Avionics)
OI-4601	External Aircraft/UAS Threat Protection	Out of initial scope (not ATM-related Avionics)
OI-5111	Advanced Winter Weather Operations - Level 3	Out of initial scope (not ATM-related Avionics)
OI-6012	Implement NextGen Environmental Engine and Aircraft Technologies – Level 1	Not Avionics
OI-6017	Increased use of Alternative Aviation Fuels	Not Avionics

Appendix 4: Risks and Benefits Assessment of the Roadmap Operational Capabilities

INTRODUCTION

The ordering of changes leading to the Next Generation Air Transportation System (NextGen) is driven by the need to solve pressing problems and constrained by maturity and development and implementation times. Priorities for the Avionics Roadmap development, based on an initial assessment of benefits and risk, are grouped as top-priorities for mid-term implementation and top priorities for research that will lead to mid- or long-term implementation.

The next steps that can be taken toward NextGen are for mid-term implementation. Top priorities are those that provide quantified high benefit by solving pressing problems and are low risk because they have matured through significant development—with understood avionics and ANS systems and procedures.

To facilitate further evaluation and emergence of aviation community consensus, this Avionics Roadmap proposes top priorities derived by a transparent data-driven assessment intended to be updated as new information becomes available. A joint industry/government team of operators, engineers, and analysts developed the assessments, representing JPDO's Aircraft, Air Navigation Services, and Safety Working Groups (WGs) and the Interagency Portfolio and System Analysis Division . The Benefits and Priorities Appendix lists key challenges and problems that have been identified by JPDO, quantifies the benefit of proposed high priority capabilities, characterizes risks, and identifies the priority assessments for the Avionics Roadmap.

The initial assessment of benefits and risks is being used to guide maturation of the Roadmap. Emphasis will be given to the capabilities noted below in terms of identifying improved interface and integration of work between the JPDO Aircraft WG and other groups and organizations involved in work related to these capabilities. By putting emphasis (priority) on these areas it is recognized that the right decision for NextGen will come from merging multiple perspectives – this Roadmap provides an initial aircraft perspective.

Overviews of the proposed capabilities and associated key enablers are provided on pages 8-19. Grouped here by the key problems they address and the affected aircraft, these proposed top priorities for mid-term implementation are:

Problem	Who	Capability (Key Enabler)
In busy metropolitan areas, airport flows interfere, constraining throughput	Aircraft in Select High Density Airspace	PRP-002 Integrated Arrival/Departure Management (Area Navigation [*RNAV*])
	Aircraft in Select High Density Arrival / Departure Airspace	PRP-001 2D RNP with Curved Segments – Reduce Lateral Track Spacing using RNP (*RNP Arrival/Departure with Radius-to-Fix (RF) Legs*)
Limits on sector capacity due to complexity and workload	Aircraft in High Density Airspace	ATM-002 Data Link En Route Clearance Delivery and Frequency Changes *(Initial Data Communications)*

Problem	Who	Capability (Key Enabler)
Safety, (security and national defense [not addressed]) must be sustained or improved *Reduce runway incursions*	Aircraft at High Density Airports	SAFE-005 Surface Collision Avoidance: Aircraft-based *(Surface Moving Map with Own Ship, Display of Traffic, and Advisories)*
Increase safety and reduce transgressions into restricted airspace	Any; Primarily Small Aircraft	NIP – On Demand NAS Information, SAFE-002 Weather Avoidance, SAFE-006 Airspace Avoidance, Traffic Display *(Flight Information Services – Broadcast (FIS-B) & Display of Traffic)*
The total system must be economical	Aircraft over Gulf of Mexico	PRP-007 Reduced Oceanic and Non-Radar Separation (Gulf of Mexico) *(Automatic Dependent Surveillance – Broadcast (ADS-B) Out for Non-Radar Separation)*
	Aircraft at High and Moderate Density Airports	NT-003 Initial Surface Traffic Management *(Air Traffic Management and Ramp)*

A further step that can be taken toward NextGen is for the early completion of research that leads to mid- or far-term implementation. Grouped by the problems they solve and the affected aircraft, the proposed key types of improvements or alternatives, and the issues that must be resolved are:

Problem	Who	Capability	Selected Issues
Inability to fully utilize individual runway capacity	Aircraft in High Density Airports	CDTI-Assisted Visual Separation (CAVS) in Marginal Meteorological Conditions (MMC) conditions DS-008 Enhanced Visual Approach *(MMC-Certified CAVS)*	The cost factor is still very much in question. Maturity of technical requirements. Level of aircraft equipage / participation necessary to realize benefits. Lead time needed for avionics development and implementation.
		DS-009 ADS-B Approach Spacing *(IMC-Certified CAVS)*	Policies, procedures, and roles are uncertain and have significant associated risk.

Problem	Who	Capability	Selected Issues
Inability to fully utilize individual runway capacity (When closely-spaced to an active parallel runway)	Aircraft on Select Close Parallels	Improved analysis and operational experience with parallel ILS approaches are used to update independent parallel approach criteria	Achievable runway spacing needs to be determined based on data and analysis.
		Use of precision navigation in combination with ADS-B to keep aircraft in front of the wake vortex of a paired approach and to mitigate against potential blunders.	Requirements for navigation and surveillance need to be determined.
In busy metropolitan areas, airport flows interfere, constraining throughput	Aircraft in Select High Density Arrival / Departure	PRP-005 3D Required Navigation Performance (RNP) Arrival and Departure Operations (RNP with Vertical Containment)	What level of vertical containment is required?
	Aircraft in Select Hi-Density Airspace	PRP-001 Reduce Lateral Track Spacing Using RNP	How close is close enough? Is ADS-B required to get the desired benefits?
		Enhanced Metering, Sequencing and Spacing: NT-005 Route Clearance with Required Time of Arrival (RTA) NT-006 Route Clearance with RTA and Downlink of Expected Trajectory NT-007 Trajectory Clearance with RTA and Downlink of Expected Trajectory NT-008 Airborne Lateral / Vertical / Time Clearances LV-011 (Airborne) Merging and Spacing	Multiple ways of performing metering, sequencing, and spacing

Problem	Who	Capability	Selected Issues
Safety, security, and national defense must be sustained or improved *Reduce runway incursions*	At High Density Airports	SAFE-005 Surface Collision Avoidance: Aircraft-based (Surface Moving Map with Alerting and/or Taxi Path)	What are the avionics requirements to enable support for these higher-criticality functions? What is the suite of solutions available for different types of airports?
Improve overall safety as NAS utilization increases	Aircraft in High Density Airspace	SAFE-004 Airborne Collision Avoidance to support NextGen operational capabilities	Operational performance parameters and requirements uncertain Controller alerting and responsibility
The total system must be economical *Excess fuel burn and pollution due to non-optimum descents*	Aircraft in High Density Arrival / Departure	Optimum Profile Descents in High-Density Traffic: PRP-004 Optimized Profile Descents (FMS Only) NT-007 Trajectory Clearance with RTA and Downlink of Expected Trajectory, DS-002 Use Optimized Profile Descents (Flight Management System + Flight Data Management System)	Multiple ways of performing optimum profile descents

METHODOLOGY FOR SELECTING THE ITEMS FOR HIGH PRIORITY MID-TERM IMPLEMENTATION, AND HIGH PRIORITY RESEARCH

The methodology employed to identify the high priority implementation and research objectives for the mid-term leveraged a rich set of data developed by the JPDO, various FAA program offices, and other aviation stakeholders. A team staffed with industry and government representatives whose perspectives encompassed aircraft operations, air navigation services, and regulatory oversight collected and evaluated the data.

Previously, the JPDO had undertaken a risk/benefit assessment of a wide range of capabilities and their associated key enablers. A principal focus of the assessment addressed the range of benefit mechanisms accruing to aircraft operators, the public and the service provider. Quantitative analysis results of the operational effects of these benefit mechanisms were collected along with monetized benefit streams when available. Since the source analyses had been conducted at different times using a range of operational and economic assumptions, the results, when possible, were normalized to support a comparative assessment of the benefit contributions of the various capabilities.

Another consideration in the analysis was that capabilities were assessed pertaining to their maturity from policy, business, operational, and technical perspectives. Risks were identified with regard to the likelihood that the target capabilities could be implemented and business objectives achieved within the mid-term time frame. While an explicit cost analysis for the key enablers was not done, cost considerations in terms of avionics affordability were taken into account.

The risk benefit analysis (RBA) is entitled "Delivery of Prototype Risk Benefit Analysis System" and was delivered in September 2007 to JPDO on a CD ROM and contains:

- Spreadsheet tool

- Data sheets

- References

- A methodology paper

- A set of criteria for benefit and risk evaluation

The Table 4-1 provides an assessment of all of the operational capabilities that are included in the Roadmap. The table has the following:

- **ID:** This refers to the operational capability (OC) number which is associated with the OC name.

- **Short Name:** This is a title descriptive of the OC. It also provides a list of related JPDO operational improvements (taken from the JPDO Integrated Work Plan) and items in FAA's NextGen Implementation Plan.

- **Priority Action:** There are four categories of priorities associated with each operational capability.

  o **NowGen activities:** Activities that the FAA is committed to and implementing now
  o **Mid-Term (MT) Implementation Priorities:** Recommendations of this Roadmap for priority implementation of Operational Capabilities before 2018
  o **Priority Research:** Activities that are not recommended for implementation by 2018 but where research is justified to lead to implementation prior to 2025
  o **Roadmap Items:** Items that are considered operational feasible prior to 2025 but did not make the priority list

- **Overall Risk:** This is defined as high, medium, and low. Definitions of these risks are presented at the end of this appendix. The risk benefit analysis has the risks broken into elements: Technical, Planning, Policy, Procedures and Institutional Risk, and Changes in Roles and Responsibilities. This was omitted from this document and only the overall risk is provided. The reader can refer to the RBA source presented above for the details.

- **Overall Benefit:** This is defined as high, medium, and low. Definitions of these risks are presented at the end of this appendix. These benefits were divided into domains in the original risk benefit analysis, but this level of detail was omitted from this document. The reader can refer to the RBA source presented above for the details.

- **Comments:** The comments section summarizes the rationale for the risks and benefits and is often taken from the RBA analysis mentioned above or from other sources.

- **References:** There are three types of references. The first is defined as "**RBA: title**" where the information is derived from one of the data sheets associated with the RBA assessment. This is generally a 3-10 page paper that provides both qualitative and quantitative data on the rationale for evaluating the risks and benefits. The second reference is defined as RBA matrix, where there is no data sheet, but a summary of the rationale for the risks and benefits is presented in the spreadsheet tool. The third reference is specific citations. Where there is no RBA reference, this is new information that has been collected since the RBA work was done.

This information on risks and benefits was reviewed by a Tiger Team that was established by the Aircraft WG to develop priorities. The general principle used by the tiger team was to recommend items that were of low and in a few cases moderate risk and high benefit for mid-term implementation, and high risk and high benefit for priority research. However, there were other considerations that fed into the prioritization categorization so that there is not a one-to-one match between the risk benefit assessment and results. Table 4-2 presents some cases where this was a mismatch.

The aviation community—working through a collaborative process—has identified a need for a series of near-term priority operational capabilities necessitating avionics investments. The FAA has committed itself to enabling these capabilities, as documented in the NextGen Implementation Plan.

The information that supported the priority assessment is presented below in Table 4-2.

DETAILED EVALUATION OF THE MID-TERM IMPLEMENTATION PRIORITIES

For each of the recommended mid-term implementation priorities a more detailed assessment was performed and is in the tiger team report. An evaluation of each mid-term implementation recommendation is presented in Table 4-2. The table addresses:

- What is the operational problem the capability solves? The range of problems included safety, throughput, capacity, and efficiency.
- What is the operational benefit; how is the benefit realized, how are the operational benefits quantified, and what is the data-driven confidence level for the benefit? Results for the high priority implementation recommendations are documented in Tables 4-3 through 4-8.
- What avionics, ground system, and/or procedure key enablers are required to realize the operational benefit? Key enablers for the high priority implementation recommendations are documented in Appendix 2: Key Enablers.
- Are those avionics, ground system, and/or procedure key enablers consistent with end-state designs and applications?
- What is the state of maturity for the target capability and its associated key enablers?
  - o Is the operational concept complete and with some level of acceptance in the avionic community?
  - o Have the operational and technical standards for avionics been finished? If so, what are they? If not, what activities are underway or need to be initiated to complete them?
  - o Have the operational and technical requirements for ground systems been defined? If not, what activities are underway or need to be initiated to complete them?
  - o Have the operational procedures for flight crews and controllers been defined? If not, what activities are underway or need to be initiated to complete them?
  - o Has an initial operational capability for avionics been achieved?
  - o Has an initial operational capability for ground systems been achieved?
  - o What, if any, policy decisions are needed to realize the capability? If needed, when are those policy decisions required?
  - o While an explicit cost analysis for the key enablers was not done, cost considerations in terms of avionics affordability were taken into account.

RISK AND BENEFIT ASSESSMENT CRITERIA

Benefits: Benefits were quantified (when possible – and were mostly extracted from already available documentation). When there was quantitative information, NAS-wide benefits of $100 Million (M) or more annually are considered to be high benefits, while medium benefits were considered to be between $10 M to $100 M annually, and low benefits were considered to be below $10 M annually. If there is an application that is not NAS-wide, and there is evidence that individual carriers are considering or implementing the application, the application is considered to be high benefit. Also, benefits that significantly improve safety were also considered to be a high benefit, regardless of economic value. There are cases where the benefits were considered high if the users have expressed significant interest in this capability but the dollar value did not exceed the $100. For priority research items, there is often not adequate quantification of the benefits, but based on judgment about the operational concept the authors postulated that the benefits could exceed $100 M per year.

Risk Assessment: The risk assessment methodology is presented on the next page.

Risk Assessment Methodology from the PMD/RBA*

Risks are assessed based on *residual* risk after mitigations that are in hand are applied, and should reflect either current (not yet mitigated) risk levels or the difficulty for providing the additional needed mitigation. **Overall Risk** is assessed based on the levels of the four component risks. It should be the worst preponderance of the sub ratings; it may be better than no more than one sub-rating and no more than one degree except that plan and PPI count as one. The sole other exception is that a high PPI risk due solely to institutional issues is not considered a "show stopper" for implementation, as this is deemed to be within JPDO's range of influence to resolve.

PPI	Policy	Procedures	Institutional
Green	Low – No change in policy or no policy needed	Low – Procedures in place or have been developed	Low – Full agency and stakeholders support; benefits aligned with required investment and control
Yellow	Medium – Policy resolution planned for a specific date	Medium – Procedures understood or in development	Medium – Misalignment between can and want to make it happen
Red	High Controversial policy issue must be resolved	High Procedures are undefined or major change from current procedures	High Established lack of trust or entrenched positions exist

Technical Risk	
Green	Low – systems exist or standards exist
Yellow	Medium – systems proven in laboratory or operational test or standards being developed; development needed
Red	High – concept has not been proven or is not adequately specified or research is needed

Planning Risk	
Green	Low – program in place, resources adequate, and schedule is possible
Yellow	Medium – program not in place or resources are not adequate but schedule is doable
Red	High – schedule is impossible even if resources would be available

Changing Roles	
Green	Low – Stakeholder still has same scope of responsibilities but may be done in new ways but no change in roles
Yellow	Medium – Significant changes in how responsibilities carried out or limited changes in roles
Red	High – Significant changes in roles

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Table 4-1. Priority Assessments

ID	New Short Name	Priority Action	Overall Risk	Overall Benefit	Comments
Safety Enhancements/Hazard Avoidance & Mitigation					
SAFE-001	**Enhanced Low Altitude Operations**	NowGen	L	M	This is operating in Alaska and uses RNP or WAAS. Benefits have not been quantified but for mountainous areas where VOR coverage is limited this provides a significant reduction in altitude and more airspace access.
	OI -3010 Reduced Controlled Flight into terrain				
SAFE-002	**Weather Avoidance**				
	Weather Avoidance (GA and via ADS-B link) NIP: On-Demand information	MT Implementation Priority	L	H	SBS Program Office estimates FIS-B and ADS-B based traffic situational awareness will yield $1,673M (FIS-B) and $720M (Traffic) in user benefit between FY08-35. Risk is low because this has been demontrated and operationally test in Alaska and on the East Coast of CONUS.
	Weather sensing and digital communications networks (broadcast and request/reply)	Roadmap			Not evaluated
SAFE-003	**Obstacle Avoidance**	Roadmap item			Not evaluated
	OI -3010 Reduced Controlled Flight into terrain				
SAFE-004	**Airborne Collision Avoidance**	Priority Research	H	H	Many of the future NextGen concepts involve spacing aircraft much closer together than is currently done today and with today's collision avoidance system, this would result in far to many false alerts. Thus, a new airborne collision avoidance system is needed to enable many of the longer-term concepts to be implemented.
SAFE-005	**Surface Collision Avoidance**	MT Implementation Priority and Priority Research			
	Ground-based and On-board Runway situational awareness with ownship position and display of proximate traffic. NIP: Provide full surface situation Information (FT)	MT Implementation Priority	L	H	Somewhere between 28-46% of runway incursion errors could be avoided if the pilots knew exactly where they were on the runway surface and some additional runway incursion errors could be avoided by having prxomate traffic displayed on this surface moving map. FAA is committed to implementing these capabilities and has concluded that the risks are low.
	OI-0332 Ground-based and On-board Runway Incursion Alerting Equipment	Priority Research	M	H	NASA's analysis indicates that nearly all runway incursion could be eliminated with display of taxi routing information, alerting of potential runway incursions and ownship position on the ruwnay.
SAFE-006	**Airspace Avoidance**				
	Airspace Avoidance (TIS-B and FIS-B) NIP: On-Demand NAS information (C-ATM)	MT Implementation Priority	L	H	SBS Program Office estimates FIS-B and ADS-B based traffic situational awareness will yield $1,673M (FIS-B) and $720M (Traffic) in user benefit between FY08-35. Risk is low because this has been demontrated and operationally test in Alaska and on the East Coast of CONUS.
	Airspace Avoidance--Sending up information about airspace changes OI-0366. Dynamic Airspace Reclassification OI-0368. Flow Corridors - Level 2 Dynamic.	Roadmap item	H	L	The OIs (OI-0366 and OI-0368) that deal with fully dynamic airspace configuration are presented as low benefit because there is no clear understanding of what the marginal improvement is over the limited dynamic capability. Also the risks are high because of the complexity of providing this dynamic information to pilots without major increases in avionic costs, managing fullhy dynamic changes and addressing environmental issues.

ID	New Short Name	Priority Action	Overall Risk	Overall Benefit	Comments
SAFE-007	**Wake Avoidance & Mitigation: Combination Air and Ground**	Part of closely spaced parallel approaches	H	H	See issues of CSPA
SAFE-008	**Wake Avoidance & Mitigation: Aircraft Based**	Roadmap item	H	unk	It is not clear after addressing wake issues with OC#009 and extending visual operations using ADS-B/CDTI what the marginal value of improving the aircraft will be to avoid wake.
	Publish Routes and Procedures				
PRP-001	**Reduce Lateral Track Spacing Using RNP**	MT Implementation Priority and Priority Research			
	2D RNP with Curved Segments – 2-001 Reduce Lateral Track Spacing using RNP (RNP Arrival/Departure with Radius-to-Fix (RF) Legs)	MT Implementation Priority	L	H	CAASD estimate of benefits are in the 10's of millions per year. The risk is relatively low since avionics exists to perform these curved segment approaches but the standards still need to be developed and are in the process of being developed.
	OI-0348 Reduced Separation – High Density Terminal, Less Than 3 Miles	Priority Research	H	H	The major benefit associated with less than 3 nmi in the terminal area is that it has the potential to deconflict airspace which will permit the better utilization of existing runways and the expanded use of additional runways. Building additional runways can add capacity only if the airspace is deconflicted so that the aircraft have unrestricted access to these runways in a safe manner. The risks are high because obtaining separation distances of less than 3nmi requires major changes in procedures, avionics and increased levels of safety assurance.
PRP-002	**Integrated Arrival/Departure Airspace Management**	MT Implementation Priority and NowGen	M	H	
	OI-0311 Enhanced Arrival/Departure Routing and Access	NowGen	L	M	There are many airports where increased used of RNAV is being implemented (NY Airspace, Houston, Chicago, etc.). This capability alone will provide improvement but is not judged as high until integration is done with other capabilities such as extending the terminal area, providing extension of 3 nmi separation as well as limited dynamic airspace flexibility which is defined in OC-PRP-002b)
	NIP: Integrated Arrival/ Departure Airspace Management (HD)	MT Implementation Priority	M	H	Enables more routes in congested airspace to meet demand and allow flexibility. Underutilized airspace can be used quickly and effectively to keep the system moving when other areas become busy or impacted by adverse weather. (Benefits are estimated at $4.5B through 2024 over 9 locations) [8]
PRP-003	**Closed Loop Parallel Offsets for Time of Arrival Control**	Roadmap item			Not evaluated
	NIP: Three dimensional Path Arrival Management (3D PAM) demonstration at DEN				
PRP-004	**Optimized Descent Profiles (FMS Only)**	NowGen and Priority Research			
	OI-309 Limited Continuous Descent Arrival NIP: Use Optimized Descent Profiles (FT) NIP: Continuous Descent Arrivals at ATL a	NowGen	L	M	Today there are optimized descent profiles using RNAV-1 and VNAV at selected airports and these will be expanded to other airports in the future. To achieve higher benefits the capability will have to feasible at more airports with more complex traffic and higher densities. This is described in OC PRP-004b.
	OI-0330 Time-Based and Metered Routes with CDA NIP: Tailored Arrivals at MIA (demonstrations)	Priority Research	H	H	It is clear from the analysis of Hahn and Hoffman (2007) that CDAs can be performed today in low density traffic or under special circumstances, but today there is no way to generally apply this procedure to medium or high-density airports without enhancements to ground or airborne capability. To achieve the higher density operations will require upgrades in avionics and considerably more research

ID	New Short Name	Priority Action	Overall Risk	Overall Benefit	Comments
PRP-005	3D RNP Arrival and Departure Operations	Priority Research	H	H	Quantitative analysis has been been done on this capability but it is associated with the following taken from the two pagers "The required protected airspace would be reduced compared to today's operations. 3D RNP procedures could be designed with no level segments, thereby enabling a non-idle descent variation of a CDA. Alternatively, the procedure designer could create two sequential waypoints with the same altitude constraint which would require flights to level-off for proceduralizing separation, and the increased vertical predictability that 3D operations offer could allow for arrival and departure procedures to be placed closer together than in a vectoring or 2D RNAV environment.
PRP-006	Reduced Oceanic Separation– Altitude Change Pair-wise Maneuvers	Roadmap item/ recommend that it be in priority implementation	M	H	A 2007 analysis by BAE Systems indicates that the user savings per aircraft could be around $80,000/ year per aircraft ($40 M/year for 500 aircraft). If procedure could be conducted on an air traffic certified Electronic Flight Bag Class 3, the payback for the investment could be less than 3 years.
	OI-0353 Reduced Oceanic Separation - Altitude Change Pair-wise Maneuvers NIP: Oceanic In-trail Climb and Descent (TBO)				
PRP-007	Reduced Non-Radar Separation with ADS-B out (Gulf of Mexico)	MT Implementation Priority and NowGen	L	H	SBS Program Office estimated $2,320M in capacity and efficiency benefits for high altitude (AT) GOMEX users FY 08-35. SBS Program Office estimated $304M in GA efficiency and capacity benefits to GA and other low altitude users FY 08-35.
	OI-0347 Reduced Separation Non-Radar Airspace 5 Miles				
Negotiated Trajectories					
NT-001	Oceanic Airspace; Flexible Entry Timing 3-013 Oceanic Airspace; Flexible Entry Timing	Roadmap item	L	M	Fuel savings and additional cargo revenue is approximately $48 million per year
	OI-0304 Improved Collaborative Oceanic Routing NIP: Flexible Entry Times for Ocean				
NT-002	Overhead Flow; Flexible Entry Timing	Roadmap item			Not evaluated
NT-003	Initial Surface Traffic Management	MT Implementation Priority	L	H	Total discounted life cycle benefits exceed $250 million dollars with benefit/cost ratios exceeding 6 to 1. Being operated today at Memphis used used by FedEx with significant reductions in taxi-time out.
	OI-0320- Surface Management -Level 1 NIP: Initial Surface Traffic Management (HD)				
NT-004	Terminal Airspace; Flexible Entry Timing	Roadmap item			Not evaluated
NT-005	Route Clearance with RTA	Priority Research	M	H	The risks are high because of the costs associated with integration of the data communications with the FMS and the FMS upgrades to provide RTA capability is extremely expensive (in the multiple billions of dollars) and the cost to provide the safety assurance level on the ground infrastructure is also likely to be large. Also, the marginal benefits of these capabilities are postulated to be high by JPDO and SESAR but there is little quantitative information to support these claims with the exception of providing a large improvement in controller productivity.
NT-006	Route Clearance with RTA and Downlink of Expected Trajectory	Priority Research	H	H	
NT-007	Trajectory Clearance with RTA and Downlink of Expected Trajectory	Priority Research	H	H	
	OI-0357 Trajectory Based Management – Level 1 Route/Trajectory Digital Exchange				
	OI-0358 Trajectory Based Management – Level 2 Trajectory Based Decision Support				
	OI-0360 Trajectory-Based Mgmt – Level 3 Automation-Assisted Trajectory Negotiation				
	OI-0369 Trajectory Based Management – Level 4 Automated Negotiation/Separation Management				

ID	New Short Name	Priority Action	Overall Risk	Overall Benefit	Comments
NT-009	**Airborne Lateral/Vertical/Time Clearance**	Roadmap item	H	H	See above
NT-010	**Taxi Lateral / Time Clearance**	Roadmap item	H	H	See above
	OI-0357 Trajectory Based Management – Level 1 Route/Trajectory Digital Exchange				
	OI-0358 Trajectory Based Management – Level 2 Trajectory Based Decision Support				
	OI-0360 Trajectory-Based Mgmt – Level 3 Automation-Assisted Trajectory Negotiation				
	OI-0369 Trajectory Based Management – Level 4 Automated Negotiation/Separation Management				
	OI-0370 Trajectory Based Management – Level 5 Full Gate-to-Gate				
	Delegated Separation				
DS-001	**Merging and Spacing**	Priority Research	M	H	Key purposes of the application are to reduce controller workload and to reduce inter-arrival variance, thereby allowing reduced average inter-arrival times and increasing runway throughput. While the reduction in controller instructions / workload for similar applications has widespread documentation, the validity of the specific application in achieving higher throughput is not well documented in literature. Detailed presentation of workload reduction estimates from simulation is provided by the references. Risks are medium because this is being implemented today by UPS in a limited form.
	OI-0326 Airborne Merging and Spacing – Single Runway NIP: Delegated Responsibility for Separation (TBO)				
	OI-0338, OI-0355, OI-0333 More complex forms of merging and spacing				
DS-002	**Use Optimized Profile Descents (ADS-B/CDTI and ground-based metering)**	NowGen and Priority Research			
	At SDF with UPS	NowGen			Being implemented today by UPS
	OI-0329 Airborne Merging and Spacing leading to CDA in higher-density and/or complex airspace	Priority Research	H	H	See discussion associated 2-004b
DS-003	**Delegated Separation for Specific Operations**	Roadmap item	H	M	The benefits associated with these capabilities over and beyond that which occurs with merging and spacing (which is essentially a more complex clearance and not delegation) and enhanced visual approach and IMC CAVS is very uncertain so the benefit was marked as medium. The risks of delegation of responsibility to the pilot is considered high because of issues associated with pilot responsibility and the integrity of the avionics and the separation assurance algorithms.
	OI-0356 Delegated Separation – Pair-wise				
	OI-0359 Delegated Separation – Oceanic				
DS-004	**Delegated Separation for Complex Operations**	Roadmap item	H	M	
	OI-0363 Delegated Separation – Complex				
DS-005	**Delegated Separation in Flow Corridors**	Roadmap item	H	M	
	OI-0337 Flow Corridors – Level 1 Static				
	OI-0368 Flow Corridors – Level 2 Dynamic				
DS-006	**Paired Approach in IMC to Closely Spaced Parallel Runways (includes depend approaches)**	Priority Research	H	H	The potential benefits of this application are large enough to be a likely incentive to the AC users to consider purchasing the required avionics. About 15 extra arrivals per hour can be achieved over existing procedures (i.e., with single runway operations in IMC, when runway spacing is less than 1200 ft). At the OEP airports, 35 out of 48 runway pairs below 2500 ft spacing are less than 1200 ft apart. Another major benefit of this application is the potential to pave-in-between which means that for some airports a new runway can be built between 2 runways that are now 4300 feet apart. risks are significant because of the performance requirements to operate at these closely -spaced conditions.
	OI-0335 Dependent Multiple Approaches in IMC (005)				

ID	New Short Name	Priority Action	Overall Risk	Overall Benefit	Comments
DS-007	**Independent IMC Approaches to Closely Spaced Parallel Runways**	Priority Research	**H**	unk	Producing independent closely-spaced parallels is likely to be more demanding than the paired or linked approach concept because there is no spacing to protect against blunders and no wake protection distance calculated. Alsol the marginal benefits of independent over paired operations has not been adequately evaluated.
	OI-0334 Independent Parallel or Converging Approaches in IMC NIP: Improved Operations to Closely-Spaced Parallel Runways				
DS-008	**Enhanced Visual Approach**	NowGen			Operational approval has been granted to UPS at SDF.
	OI-0316 Enhanced Visual Separation for Successive Approaches NIP: Delegated responsbility for Separation				
DS-009	**ADS-B Approach Spacing**	Priority Research	**H**	**H**	These results show an increase between 2 and 15 operations per runway per hour depending on the final separations that the pilots are comfortable maintaining using IMC CAVS. Benefits results range from $38 million per year to $600 million per year depending on the amount of equipage and what is factored into the analysis.
DS-010	**Deconflicted Missed Approaches for Converging**	Roadmap item			Not addressed
	Low-Visibility/Ceiling Approach /Departure/Taxi				
LV-001	**Low Visibility/Ceiling Approach Operations**	NowGen (EVS)/ Priority research (GBAS)	**M**	**M**	This analysis indicates that the major benefits of LAAS in the US is not in achieving CAT I but in CAT III. However, the uncertainty in the cost of a CAT III via LAAS or other methods (e.g., EVS) means that the costs may not cover the benefits. FAA's commitment is to developing standards and supporting research and the burden for avionics development is borne by industry. This is labelled a high priority research area because representatives from industry believe that not all the important benefits have been assessed adequately.
	OI-381 Near-all Weather Airport Access NIP: Ground-based augmentation System (GBAS)				
LV-002	**Low Visibility/Ceiling Landing Operations**	Roadmap item	**H**	**L**	The benefits associated with all weather airport access operations is considered low because zero-zero weather happens so infrequently. The benefits associated with all weather conditions as compared to near-all weather conditions are low because it happens so rarely in the US. However, worldwide, the benefits could be larger.
	OI-0317 All Weather Airport Access				
LV-003	**Low Visibility/Ceiling Takeoff Operations**	Roadmap item			Not evaluated
	OI-381 Near-all Weather Airport Access				
LV-004	**Low Visibility Surface Operations**	Roadmap item	**H**	**L**	See above (5-002)
	OI-0322 Low Visibility Surface Operations				
	ATM Efficiencies				
ATM-001	**Data Link Departure Taxi Clearance and Pre-departure Clearance**		**H****	**H**	**Adding new capabilities to the data link standards is a high risk for the mid-term and the marginal benefits of providing this information over what is provided today is not clear. However, there is some indication that the benefits could be high by providing taxi clearance displays to the cockpit which will improve runway safety concerns. Also, there is evidence that the time to trasmit taxi clearance changes by voice results in surface movement inefficiencies, Risks are considerably less if the standards are targetted for the longer-term.
	OI-0321 Surface Management – Level 2 Datalink/Departures NIP: Enhanced Surface Traffic Operations				

ID	New Short Name	Priority Action	Overall Risk	Overall Benefit	Comments
ATM-002	Data Link En Route Clearance Delivery and Frequency Changes	MT Implementation Priority	L**	H	** Note: The risks are high for the policies that incentivize avionics equipage so if this is not addressed the risk is high. Technically this operation has been tested in Miami and is being deployed in Europe. Benefits are improved Controller Productivity (up to 14%). Annual savings to FAA is estimated to be just under $100 million per year and to users by 2022 $220 million per year; Several analyses indicate that approximately 20% of all en route operational errors (OEs) are communications related. With data communications, most of these OEs could be eliminated.
	OI-0352 Automated Clearance Delivery and Frequency Changes				
ATM-003	**Data Link Arrival Taxi Instructions**	Roadmap Item			Not evaluated
	OI-0327 Surface Management – Level 3 Arrivals/Winter Operations/Runway				
ATM-004	**Data Link NAS Information and Advisories**	Roadmap item			Not evaluated
ATM-005	Increase Access and Throughput at Non-Non-Towered/Uncontrolled Airports	Roadmap item	H	H	Extending this to the surface and providing "separation functions provided either by ground automation or through aircraft-based conflict detection/resolution algorithms" is a mjaor technical challenge requiring signficant R and D and development (for automated virtual towers). The benefits are high because virtual towers could provide significantly more services to the smaller airports in a metroplex area and that would relieve traffic at some of the major airports. This could be done without providing costly infrastructure.
	OI-0313 Virtual Towers – Level 1 Sequencing, Separation, and Spacing				
	OI-0315 Virtual Towers – Level 2 Sequencing, Separation, Spacing, and Surface Management				
ATM-006	**Reduce Weather Impacts through Improved Forecasting**	Roadmap item	H	H	Weather delays are more than an inconvenience; they cost the nation's airlines, cargo carriers, and other users in excess of $4 billion annually. According to FAA research, 29 peak delay days could wipe out an airline's profits for the entire year. FAA projections show a doubling to tripling of flight operations by 2025 which would further magnify the impact of bad weather on the air transportation system. If major changes are not made by 2025, there could be 87 days with delays worse than the worst day in 2004, a year when U.S. air travel was often severely impacted by weather. Based on today's estimates, perhaps as much as sixty-percent of such impacts are potentially avoidable weather situations (Sherry, 2007). This was from an avionics perspective not included as a major item because the case has not been made that improved weather sensors on the aircraft will play a major role in improving weather forecasts and thus addressing the problems mentioned above.
	OI-2020 – Weather Information Supports NextGen Implementation Goals – Level 1				
	OI-2021 - Weather Information Supports NextGen Implementation Goals – Level 2				
	OI-2022 - Weather Information Supports NextGen Implementation goals – Level 3				

Table 4-2. Detailed Evaluation of Mid-Term Implementation Priorities

Evaluation Criteria	Integrated Arrival / Departure Management (PRP-002)	2D RNP with Curved Segments (PRP-001)	Initial Surface Traffic Management (NT-003)	Data Link En Route Clearance Delivery and Frequency Changes (ATM-002)	Surface Collision Avoidance (Aircraft-based) (SAFE-005)	On Demand NAS Information (SAFE-002) (SAFE-006)	Reduced Oceanic and Non-Radar Separation (PRP-007)
Problem solved.	Throughput	Capacity	Efficiency	Capacity	Safety	Safety	Efficiency
Benefits (how realized, quantified and confidence level).	Table 4-4	Table 4-4	Table 4-8	Table 4-5	Table 4-6	Table 4-3	Table 4-3
What avionics, ground systems and/or procedures are required to support it?	Table 2-4 RNAV	Table 2-4 RNP SAAAR RNP RF Leg Capability	Table 2-2 ADS-B	Table 2-2 FANS 1/A+ FANS 2/B ATN Baseline 1	Table 2-2 ADS-B Table 2-5 CDTI Moving Map	Table 2-2 FANS 1/A+ FANS 2/B ATN Baseline 1 Table 2-5 Moving Map Table 1-6 FIS-B	Table 2-3 ADS-B Out
Are those avionics, ground systems and/or procedures consistent with end-state designs and applications?	Yes	Yes	Yes	Yes, consistent, but there will be an evolution	Yes, but may evolve to Class 3 EFB or embedded CDTI	Yes	Yes
Ops Concept done	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Avionics standards	AC 90-100A, TSO-C115, TSO-C129, TSO-C145, TSO-C146, TSO-C166, Order 8260.44, Order 7100.9	AC90-RNP	ADS-B reg, AC 20-ADSB, TSO-C154b, TSO-C166a	ICAO PANS-ATM, ICAO 9880, AC20-140, AC120-70B, DO290/2, DO-280B, ARINC 631	DO-260 + TBD for C-2 Electronic Flight Bag, combination not yet certified or approved	AC 20-149, AC 00-63C	Euro Aviation Safety Agency acceptable means of compliance 20-24
Ground systems requirements defined	TBD	Yes	Yes (as implemented at FedEx)	DO290/2 & DO-280B	Yes	Yes	Yes

Evaluation Criteria	Integrated Arrival / Departure Management (PRP-002)	2D RNP with Curved Segments (PRP-001)	Initial Surface Traffic Management (NT-003)	Data Link En Route Clearance Delivery and Frequency Changes (ATM-002)	Surface Collision Avoidance (Aircraft-based) (SAFE-005)	On Demand NAS Information (SAFE-002) (SAFE-006)	Reduced Oceanic and Non-Radar Separation (PRP-007)
Procedures defined	TBD	In process	Yes	Yes	Yes	Yes	Yes
Equipage Initial Operational Capability?	TBD	Exists today	Latest NGIP has this mid-term	European mandate 2011	Exists today	Exists today	Exists today
Ground system Initial Operational Capability?	Latest NGIP has this mid-term	Exists	Latest NGIP has this mid-term	~2014	Exists	2011	2011
What other operational capabilities do these avionics, ground systems and/or procedures support?	TBD	TBD	TBD	TBD	TBD	TBD	TBD

A more detailed presentation than in Table 4-2 of the benefits of each of the mid-term implementation priorities is presented in Tables 4-3 through 4-8.

Table 4-3. ADS-B Out Benefits Substantiation

Avionics	Capability	User Class	Airspace User	FAA	Society
ADS-B Out (1090ES or UAT) GPS position source	PRP-007 Reduced Non-Radar Separation (ADS-B Out for Non-Radar Separation)	AT and high-end GA	SBS Program Office estimated $2,320M in capacity and efficiency benefits for high altitude (AT) GOMEX users FY 08-35 [1] SBS Program Office estimated $304M in GA efficiency and capacity benefits to GA and other low altitude users FY 08-35 [2]	SBS Program Office estimates savings in radar replacement and installation of new radars of 1.26 billion dollars between 08-35 [3]	Provides increased safety resulting from increased provision of IFR services in areas that currently do not have radar and for improved search and rescue resulting in areas without radar services. [4]
	OEP: On Demand NAS Information, SAFE-002 Weather Avoidance, SAFE-006 Airspace Avoidance, Traffic Display (FIS-B and Display of Traffic)	Mostly GA			Reduced GA weather related accidents due to improved weather situational awareness Reduced GA mid-air collisions and near-miss incidents due to improved traffic situational awareness SBS Program Office estimates FIS-B and ADS-B based traffic situational awareness will yield $1,673M (FIS-B) and $720M (Traffic) in user benefit between FY08-35 [5]
	Improved Surface Traffic Management	All	With ADS-B Out the tower as well as the RAMP personnel can see the aircraft and better manage surface operations thus reducing taxi times. Also, there are times when ASDE-X is not effective (during heavy precipitation) and ADS-B is effective. The SBS office projects a FY08-35 benefit of around $100 million. [6] However, this is not complete because it doesn't address other airports and benefits to the users by having the RAMP area surveilled. Surveillance and Broadcast Services Benefits Basis of Estimate; Table 2-14; August 2007		

Table 4-4. RNP and RNAV Benefits Substantiation

Avionics	Capability	User Class	Airspace User	FAA	Society
RNP-1 and 0.3 navigation capability with RF Legs	2D RNP with Curved Segments – PRP-001 Reduce Lateral Track Spacing using RNP (RNP Approach/Departure/Arrival with RF Legs)	AT and high-end GA	De-conflicting arrivals and departures for adjacent airports Improved access to under-utilized runways Improves access to airports during IFR conditions where there are obstacles to straight in approaches CAASD estimate of benefits are in the 10's of millions per year [7]	Reduced controller workload from reducing vectoring and communications	Enhanced safety through guidance to the runway and terrain avoidance Fuel and emissions benefits from improved descent continuity and shorter paths Reduced incidents of runway "excursions" Better access to secondary airports and improved ability to transit high density airspace.
RNAV required for specific airports	PRP-002 Integrated Arrival/Departure Management (RNAV)	AT and high-end GA	Enables more routes in congested airspace to meet demand and allow flexibility. Underutilized airspace can be used quickly and effectively to keep the system moving when other areas become busy or impacted by adverse weather. ($4.5B through 2024 over 9 locations) [8]	Reduced controller workload from reducing vectoring and communications	Fuel and emissions benefits from reduced delays and less vectoring

Table 4-5. Data Link Segment 1 Benefits Substantiation

Avionics	Capability	User Class	Airspace User	FAA	Society
VDL-2 Transceiver, CMU, and display integration FANS 1/A or ATN Baseline 1 Applications FMS integration desired but not required	ATM-002 Data Link En Route Clearance Delivery and Frequency Changes		Improved Operational Efficiency in Convective Weather [9] Reduced Fuel Usage and Related Costs through reduction in delay [9] Annual savings to airlines in 2022 is estimated to be over $200 M per year [9]	Improved Controller Productivity (up to 14%) [10] Annual savings to FAA is estimated to be just under $100 million per year [9]	Several analyses indicate that approximately 20% of all en route operational errors (OEs) are communications related. With data communications, most of these OEs could be eliminated [9]

Table 4-6. Surface Moving Map and /or Runway Awareness and Advisory System (RAAS) Benefits Substantiation

Avionics	Capability	User Class	Airspace User	FAA	Society
Class 2 EFB or MFD/PFD GPS position source (probably SBAS enhanced ADS-B In (1090ES or UAT) and/or RAAS avionics	SAFE-005 Surface Collision Avoidance: Aircraft-based	All	There is some indication that moving maps provide the pilot with better information about taxiway exits and thus speeds up their exit time on the runway. Not clear that will apply to Class 2 devices.		Reduction in runway incursions: between 28% and 95%. [11]. RAAS provides 46% mitigation for wrong runway departures but data not found on overall runway incursions [11].

Table 4-7. ADS-B In Benefits Substantiation

Avionics	Capability	User Class	Airspace User	FAA	Society
Leader Aircraft: ADS-B Out (Assumed 1090ES) GPS possibly SBAS position source Follower Aircraft: ADS-B In (Assumed 1090 ES) GPS possibly SBAS position source CDTI with CSPA application ILS, LPV or GLS	DS-006 Paired Approach in IMC to Closely Spaced Parallel Runways	AT and high-end GA	Higher capacity and throughput to closely-spaced parallel runways even during low visibility (initial implementation may be high ceilings) There are 48 runway pairs in the NAS currently spaced between 700 and 2500 feet. that could in principle use the procedure New runways 700 feet from existing runways on largely existing airport property could probably be built at 18 landlocked airports that could also use the procedure [12] Benefits are significant (TBD)		Reduced delays results in reduced fuel use and emissions
Leader Aircraft ADS-B Out GPS position source Follower Aircraft ADS-B In CDTI with CAVS Application GPS position source	CAVS in MMC conditions – DS-008 Enhanced Visual Approach	AT and high-end GA	Increased opportunities to land at near VMC capacities during MMC For advanced versions of procedure, operations may increase arrival rates to parallel or converging runways Benefits for initial Marginal VMC CAVS of $600M/ year [13]	Operating in visual conditions is generally less workload for the controllers	Reduced delays results in reduced fuel use and emissions

Table 4-8. Surface Traffic Management System Benefits Substantiation

Avionics	Capability	User Class	Airspace User	FAA	Society
Mode- C or Mode-S and/or ADS-B Out	NT-003 Initial Surface Traffic Management (ATM and Ramp)	All	Average taxi-out time for FedEx aircraft is 1.3 minutes less with surveillance during VA conditions and 4.3 minutes less with surveillance during IA conditions using surveillance outage data when MEM in North Flow operation. Also percentage of taxi-out times that are greater than 40 minutes decreases by at least half. No significant change in taxi-out during South Flow. [14] Total discounted life cycle benefits exceed $250 million dollars with benefit/cost ratios exceeding 6 to 1. [15]		Reduced emission from less taxi times and better gate management

KEY ENABLER BENEFITS SUBSTANTIATION REFERENCES

1-6   Surveillance and Broadcast Services Benefits Basis of Estimate; August 2007.

7   MITRE/CAASD estimated based on information presented in the Performance-based operations Aviation Rulemaking Committee report entitled "Applications and Priorities for RNP Instrument Approach procedure Implementation Report," February 2005.

8   Federal Aviation Administration (FAA), Air Traffic Organization Operations Planning "Integrated Arrival/Departure Control Service (Big Airspace) Concept Validation," September 2007.

9   FAA, ATO-W, "Benefits Basis of Estimate, Data Communications Program, Initial Investment Analysis" v0.04, July 2008.

10   MITRE/CAASD, "Data Link Benefit-Cost Analysis Methodology," MTR04W0000081R1, September 2005.

11   From Aviation Week and Space Technology, April 7, 2008 (p.47). "About 55 percent of Class A and B types are caused by pilot deviation—that is, the aircraft is maneuvered to the wrong location. The improved situational awareness of an airport moving map with the aircraft's position marked could eliminate half of these types of mishaps, according to the CAST findings. The other 45 percent of mishaps could be addressed only when it is possible to show pilots where other surface traffic is located." *CAST determined that 95 percent of all runway incursions could be prevented* by having (1) a cockpit moving map display with own-ship position for improved situational awareness, (2) integration of ADS-B to enable pilots and controllers to see all aircraft and vehicles on the surface and aircraft up to 1,000 feet above ground level, (3) automatic runway occupancy alerting, and, (4) digital data-linked clearances that are then displayed on the moving map (ALPA, White Paper: Runway Incursions A Call to Action, March 2007). Thus ownship with proximate traffic would lie between the 28 percent value and the 95 percent value. Glenn Michaels in his briefing entitled "FAA Call to Action on Runway Safety Short-term Actions presents" the JIMDAT Mitigation Assessment as about 46 percent reduction utilization of the wrong runway. However, the assessment of RAAS is similar for using the wrong departure runway.

12.   Mundra, Anand, "ADS-B/CDTI Applications Under Investigation in an Internal MITRE Research Program," March 9, 2008.

13.   A study by MCR Federal, Inc. (Safe Flight 21 CDTI Enhanced Flight Rules (CEFR) Initial Benefit Analysis (Version 3, May 2003)) evaluated the potential benefits of this application. The results show a $315 M annual savings at the top 31 busiest airports. This is a conservative estimate because the MCR study assessed benefits according to the actual airports' VMC rules that fall heterogeneously between two scenarios: Level Two CFR (visibility >= 5 mi and ceiling >= 3000 ft) and Level Three CFR (visibility >= 3 mi and ceiling >= 1000 ft). Cirillo notes that the delay savings benefit of the Level Three CFR scenario is double that of Level Two CFR scenario (Cirillo, M., 2002, AW-2: Space Closer to Visual Standards / CDTI-Enhanced Flight Rules –Decision Status, Washington, DC: Federal Aviation Administration).

14.   Howell, Dan, Effect of Surface Surveillance Data Sharing on FedEx Operations at Memphis International Airport, ATC Quarterly, Modified July 4, 2007.

15.   Atkins, Stephen et al, Surface Management System Field Trial Results, AIAA 4th Aviation Technology, Integration and Operations (ATIO) Forum, 20 - 22 September 2004, Chicago, IL.

Appendix 5: Key Policy Issues Associated with the Roadmap Operational Capabilities

The following table identifies Next Generation Air Transportation System policy issues (as identified in the Integrated Work Plan) that impact near- and mid-term aircraft capabilities. Policy issues that will impact long-term capabilities will be identified in future versions of the Avionics Roadmap.

Table 5-1. Key Policy Issues and Roadmap Operational Capability Impacts

IWP Policy	Description	Affected Capabilities
PI-0004	ATM Automation Development, Performance and Interoperability Standards	SAFE-007: Wake Avoidance and Mitigation – Air/Ground Combination NT-005: Route Clearance with RTA NT-006: Route Clearance with RTA and Downlink of Expected Trajectory NT-008: Airborne Lateral/Vertical/Time Clearance NT-009: Taxi Lateral/Time Clearance ATM-001: Data Link Pre-departure Clearance Revisions ATM-002: Data Link En Route Clearance Delivery and Frequency Changes ATM-003: Data Link Taxi Instructions
PI-0007	Rules of the Road (Priority access to equipped aircraft)	All closely-spaced parallel approach and delegated separation (DS) capabilities All data link (NT) dependent applications
PI-0010	National Surveillance Strategy (including backup surveillance and ADS-B position strategies)	SAFE-004: Airborne Collision Avoidance SAFE-005: Surface Collision Avoidance DS-003: Delegated Separation for Specific Operations DS-004: Delegated Separation for Complex Operations DS-005: Delegated Separation in Flow Corridors DS-006: Paired Approach in IMC to Closely Spaced Parallel Runways DS-007: Independent IMC Approaches to Closely Spaced Parallel Runways DS-008: Enhanced Visual Approach DS-009: ADS-B Approach Spacing DS-007: Independent IMC Approaches to Closely Spaced Parallel Runways

IWP Policy	Description	Affected Capabilities
		DS-008: Enhanced Visual Approach
		DS-009: ADS-B Approach Spacing
		LV-002: Low Visibility/Ceiling Landing Operations
PI-0014	Aircraft Equipage Implementation Policy (including operational incentives, economic incentives (e.g., tax credits) and/or mandates Objective criteria should define when voluntary incentives are abandoned in favor of mandates.	All
PI-0017	Communications Architecture Plan for Ground, Space, Airborne, and/or Performance-Based Architectures – (Decision on data communications performance requirements and the utilization of specific system and/or performance based systems)	NT-005: Route Clearance with RTA
		NT-006: Route Clearance with RTA and Downlink of Expected Trajectory
		NT-008: Airborne Lateral/Vertical/Time Clearance
		NT-009: Taxi Lateral/Time Clearance
		ATM-001: Data Link Pre-departure Clearance Revisions
		ATM-002: Data Link En Route Clearance Delivery and Frequency Changes
		ATM-003: Data Link Taxi Instructions
		ATM-004: Data Link NAS Information and Advisories
		ATM-005: Increase Access and Throughput at Non-Towered/Uncontrolled Airports
		ATM-006: Reduce Weather Impacts through Improved Forecasting
PI-0088	Federal vs. Private Role In Weather Services (including fee vs. no-fee government services)	SAFE-002: Weather Avoidance
PI-0101	Initial Aviation Environmental Policy (environmental standards and streamline environmental review processes)	PRP-002: Integrated Arrival/Departure Airspace Management
PI-0115	NextGen Safety Assessment/Certification - Synchronized and/or Integrated Aircraft and ANS Capabilities and Certification Standards	SAFE-007: Wake Avoidance and Mitigation – Air/Ground Combination
		SAFE-008: Wake Avoidance and Mitigation – Aircraft-Based
		PRP-006: Reduced Oceanic Separation – Altitude Change Pair-wise Maneuvers
		DS-003: Delegated Separation for Specific

IWP Policy	Description	Affected Capabilities
		Operations
		DS-004: Delegated Separation for Complex Operations
		DS-005: Delegated Separation in Flow Corridors
		DS-006: Paired Approach in IMC to Closely Spaced Parallel Runways
		DS-007: Independent IMC Approaches to Closely Spaced Parallel Runways
		DS-008: Enhanced Visual Approach
		DS-009: ADS-B Approach Spacing

Appendix 6: Aircraft Working Group Participants and Support Staff

The Aircraft Working Group (WG) members that participated in at least one scheduled meeting of the WG
(October 2007 – October 2008) are listed in Tables 6-1 and 6-2.

Table 6-1. Participants of the Aircraft Working Group

Name	Agency/Company
Kathy Abbott	FAA
Frank Alexander	Northwest Airlines
Chad Balentine	ALPA
Clay Barber	Garmin
Chris Benich	Honeywell
Randy Bregger	Bell Helicopter
Hank Cabler	FAA
Mike Cramer	MITRE
Bruce DeCleene	FAA
Colleen Donovan	FAA
Jim Duke	ALPA
Charles Durkin	Day Jet Corp.
Jeff Duven	FAA
Kristin Farry	Excalibur/AOPA
Scott Foose	RAA
Mark Fox	FAA
Steven Hampton	ERAU
Richard Heinrich	Rockwell Collins, Inc.
Doug Helton	Aviation Management Associates
Stephen Jacklin	NASA
Pascal Joly	Airbus Americas
Dwayne Kimball	Hawker Beechcraft
Worth Kirkman	MITRE
Marti Klemm	ERAU
Xiaogong Lee	FAA

Frank Mangine	FAA
David Manville	U.S. Army
George Marania	FAA
Goran Mrkoci	BAE Systems
Dave Nakamura	Boeing
Rob Pappas	FAA
Dharmesh Patel	Honeywell
Art Politano	FAA
Jean-Claude Richard	Thales Avionics
Brian E. Smith	NASA
Scott Stevens	FAA
Ronald Stroup	FAA
Scott Taylor	U.S. Air Force
Don Taylor	Cumulus Consulting
Stephen Van Trees	FAA
Jeffrey Viken	NASA
Keith Wichman	GE Aviation

Table 6-2. Support Staff of the Aircraft Working Group

Name	Agency/Company
Selam Firdaweke	HMMH
Claudia Galea	Booz Allen
Eric Lautenschlager	ANSER
Sean McCourt	MITRE
Skip Monk	FAA
Joseph Palermo	Booz Allen
Trent Prange	FAA
Art Smith	MITRE
Sean Stapleton	MITRE
Todd Stock	MITRE
Rick Towle	Sensis

Appendix 7: Glossary

4D	Four-Dimensional
4DT	Four-Dimensional Trajectory
AC	Advisory Circular
ACARS	Aircraft Communications Addressing and Reporting System
ADS-B	Automatic Dependent Surveillance-Broadcast
ADS-C	Automatic Dependent Surveillance-Contract
AIAA	American Institute of Aeronautics and Astronautics, Inc.
ALPA	Airline Pilots Association
ANP	Air Navigation Plan
ANS	Air Navigation System
ANSP	Air Navigation Service Provider
AOA	ATN Over ACARS
AOC	Airline Operational Control
AOPA	Aircraft Owners and Pilots Association
ARINC	Aeronautical Radio Incorporated
ASDE-X	Airport Surface Detection Equipment, Model X
AT	Air Traffic
ATC	Air Traffic Control
ATIO	Aviation Technology, Integration and Operations
ATM	Air Traffic Management
ATN	Aeronautical Telecommunication Network
ATO	Air Traffic Organization
CAASD	Center for Advanced Aviation System Development
CAST	Commercial Aviation Safety Team
CAVS	CDTI Assisted Visual Separation
CDA	Continuous Descent Arrival
CDROM	Compact Disc Read-Only Memory
CDTI	Cockpit Display of Traffic Information
CEFR	CDTI Enhanced Flight Rules
CFIT	Controlled Flight into Terrain
CFR	Code of Federal Regulations
CM	Configuration Management
CMU	Communications Management Unit
COI	Community of Interest
ConOps	Concept of Operations
CPDLC	Controller Pilot Data Link Communications
CSPA	Closely Spaced Parallel Approach
CTA	Controlled Time of Arrival
DS	Delegated Separation
D-TAXI	Data Link TAXI
EFB	Electronic Flight Bag
EFIS	Electronic Flight Instrument Systems
EFVS	Enhanced Flight Vision Systems
ERAU	Embry-Riddle Aeronautical University
ETA	Estimated Time of Arrival
FAA	Federal Aviation Administration
FANS	Future Air Navigation System
FCM	Flow Contingency Management
FDMS	Flight Deck-Based Merging and Spacing

FIS-B	Flight Information Service-Broadcast
FL	Flight Level
FMS	Flight Management Systems
FOC	Flight Operations Center
FY	Fiscal Year
GA	General Aviation
GBAS	Ground Based Augmentation System
GE	General Electric
GLONASS	Global Navigation Satellite System (Russia)
GLS	GPS Landing Systems
GNSS	Global Navigation Satellite System
GOMEX	Gulf of Mexico
GPS	Global Positioning System
GRAS	Ground-based Regional Augmentation System
HMI	Human-Machine Interface
HMMH	Harris Miller Miller & Hanson Inc.
HUD	Head Up Display
IA	Initial Approach
ICAO	International Civil Aviation Organization
ID	Identification
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
IWP	Integrated Work Plan
JIMDAT	Joint Implementation Measurement Data Analysis Team
JPDO	Joint Planning and Development Office
LNAV	Lateral Navigation
LPV	Localizer Performance with Vertical Guidance
LV	Low Visibility
MDCRS	Meteorological Data Collection and Reporting System
MEA	Minimum En Route (IFR) Altitude
MEM	Memphis International Airport
MFD	Multifunction Display
MMC	Marginal Meteorological Conditions
MT	Mid-Term
MVA	Minimum Vectoring Altitude
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NextGen	Next Generation Air Transportation System
NGIP	Next Generation Information Platform
NIP	NextGen Implementation Plan
NOTAM	NOTice to AirMen
NPRM	Notice of Proposed Rulemaking
NT	Negotiated Trajectory
OC	Operational Capability
OE	Operational Errors
OEP	Operational Evolution Partnership
OI	Operational Improvement
PANS	Procedures for Air Navigation Services
PARC	Performance-Based Aviation Rulemaking Committee
PBN	Performance-Based Navigation
PFD	Primary Flight Display
PRP	Published Routes and Procedures
RAA	Regional Airline Association

RAAS	Runway Awareness and Advisory System
RAMP	Ramp Manager
RBA	Risk Benefit Analysis
RF	Radius to Fix
RNAV	Area Navigation
RNP	Required Navigation Performance
RTA	Required Time of Arrival
RTCA	Radio Technical Commission for Aeronautics
RVR	Runway Visual Range
SAAAR	Special Aircrew and Aircraft Authorization Required
SAFE	Safety Enhancement/Hazard Avoidance & Mitigation
SATCOM	Satellite Communications
SBAS	Space Based Augmentation System
SBS	Surveillance and Broadcast Services
SESAR	Single European Sky ATM Research Programme
SID	Standard Instrument Departure
SM	Separation Management
STAR	Standard Terminal Arrival Routes
SUA	Special Use Airspace
SVS	Synthetic Vision Systems
SWIM	System-Wide Information Management
TBD	To Be Determined
TBO	Trajectory-Based Operations
TCAS	Traffic Alert Collision Avoidance System
TFR	Traffic Flow Restrictions
TM	Traffic Management
TSO	Technical Standard Order
UAS	Unmanned Aerial System
UAT	Universal Access Transceiver
U.S.	United States
VDL-2	VHF Digital Link Mode 2
VDR	VHF Digital Radio
VFR	Visual Flight Rules
VHF	Very High Frequency
VMC	Visual Meteorological Conditions
VNAV	Vertical Navigation